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EDITED BY

GEORGE C. LLOYD

SECRETARY

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1926

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PREFACE.

The present volume of the *Journal of the Iron and Steel Institute* contains the papers presented at the Autumn Meeting held at Stockholm in August 1926, with the discussion and correspondence thereon, to which a Report of the visits and excursions to works and mines in South and Central Sweden, made during the meeting, is appended. Section I. concludes with biographical notes on the careers of members deceased during the previous six months, published under the heading of Obituary Notices.

In Section II. will be found the usual notes on the progress of the iron and steel industries at home and abroad, with a bibliography of the more important books published during the past half-year, followed by a list of the British Standardised Steel Samples now available.

28 Victoria Street, London, S.W. 1.
December 31, 1926.

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SECTION I.

MINUTES OF PROCEEDINGS AND PAPERS OF THE IRON AND STEEL INSTITUTE.

AUTUMN MEETING

1926.

Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), Assistant Secretary, in the preparation of this Section.

MINUTES OF PROCEEDINGS

AND

PAPERS AND DISCUSSIONS

AT THE

STOCKHOLM MEETING, 1926.

The Autumn Meeting of the Iron and Steel Institute was opened on the morning of Friday, August 27, 1926, at the Palace of the Nobility (Riddarhuset), Stockholm, under the Presidency of Sir W. Peter Rylands, J.P.

Welcome by Jernkontoret.

Mr. Jonas C. Kjellberg (President of Jernkontoret) said it was his agreeable duty, on behalf of the Association of Swedish Ironmasters, to express their great appreciation of the honour shown by the President and Council in accepting the invitation of the Association to hold the Autumn Meeting of the Institute in Stockholm, and he desired to bid the members a hearty welcome. They were not only glad, but also proud, to receive them, and would endeavour to make their visit to Sweden as interesting and agreeable as possible.

Although he was well aware that the most interesting part of the meeting would be the proceedings in the venerable Palace of the Nobility, which had accommodated the memorable meeting of 1898, and was again generously placed at the disposal of the Institute for the present meeting, he expressed the hope that the members would find something of interest also in the scientific institutions and the industrial establishments to which visits had been planned during their stay in Sweden.

It was well known that the iron industry in Sweden was not on a very large scale, and that, as in other countries, it was not flourishing at present. But they had not lost hope that better

times would come, and, sustained by that hope, Swedish metallurgists, like their British colleagues, were doing their utmost by the introduction of new methods and the improvement of old ones to produce a still higher quality, and to do it in a more economical way.

They realised the leading place which the Iron and Steel Institute held in regard to the scientific and practical progress of the iron industry, and that among its members it had had, and still claimed to have, several who, with full justice, enjoyed a world-wide reputation for their knowledge and their researches.

He very much regretted the circumstances which had prevented many of the members from attending the meeting, but earnestly hoped that the present industrial dispute would soon be terminated by a satisfactory settlement, which would be an event of the greatest importance, not only for Great Britain, but for the whole world. He once more bid the members a hearty welcome.

Mr. Kristoffer Huldt (President of the Swedish Association of Engineers and Architects) said that as Jernkontoret had given Svenska Teknologforeningen (the Swedish Association of Engineers and Architects) the opportunity of associating themselves with the welcome to the members of the Institute, he thought they could do it in no better way than by giving the members an impression of the capital, Stockholm, and showing them some of the technical and scientific institutions in which their engineers were trained, and their material was investigated and tested. They hoped time would also permit of showing them establishments especially founded upon Swedish engineering technique and developed by Swedish engineering ingenuity. Though the programme must of necessity be brief and concentrated, he hoped it would interest the members, and that they would see how Sweden, although a small nation, was making every endeavour now, as in the past, to give its young men, the future engineers, the best possible training to meet coming demands. They would see that they were hard at work in all branches of technical science, and that the knowledge thus obtained was being applied to the advancement of industrial efficiency.

One of the Past-Presidents of the Institute, Sir William Ellis, had referred a year ago to the necessity for a close association

between metallurgy and engineering. He personally concurred with that statement, and desired to say in addition that Swedish engineers, and engineers the wide world over, were under a great and lasting obligation for the contributions to scientific and practical knowledge in engineering and metallurgy made during past years by the Iron and Steel Institute. He was convinced there was no exaggeration in the statement that engineers in all branches, in all countries, took full advantage of the concrete researches and work of the Iron and Steel Institute. Engineering, which knew no boundaries either on land or sea, nor even in the air, formed a link between the nations, and the problems continually arising formed a common meeting ground for their people. He expressed the hope that the visit of the members would further strengthen the bonds between Great Britain and Sweden, and between all those interested in technical science and industrial activity.

Svenska Teknologforeningen would consider it an honour if the members of the Institute would regard themselves as the Association's temporary guests, the Club Rooms and Library being at their disposal during leisure hours. He again bid the members a very hearty welcome.

Mr. J. C. Kjellberg then announced that His Majesty King Gustav had graciously directed him to express his regret that, owing to Her Majesty the Queen's illness, he could not fulfil the intention, as he had hoped, of receiving the President, the Council, and members that afternoon. He was further authorised to announce that, by His Majesty's gracious permission, the Royal Castle might be visited at four o'clock, and that the rooms and collections would be shown by competent gentlemen.

The President said that on behalf of the members of the Iron and Steel Institute he desired to thank Mr. Kjellberg and Mr. Huldt for their very cordial greetings, and for the hospitality which was being extended to them on their visit to Sweden. Sweden was especially dear to the minds of the ironmasters of Great Britain. They had always regarded Sweden as the historical source from which the great industry took its rise, and in visiting Sweden they felt they were among very good friends, who had

extended to them the right hand of fellowship, which the members in their turn most heartily reciprocated.

He desired to add that in token of their regard for their Swedish hosts the Council at their meeting held that morning had unanimously elected Mr. Kjellberg an Honorary Member of the Institute—an act which he hoped the members would consider appropriate, and an honour which he trusted Mr. Kjellberg would long live to enjoy.

Mr. Kjellberg expressed his deep sense of appreciation of the honour. He felt he did not deserve such a distinction, but he accepted it with humble thanks as a token of regard to Jernkontoret by the Iron and Steel Institute.

The President, continuing, said he was very sorry there were not so many members present from England as the Council had expected and would have desired. The President of Jernkontoret had made reference to the unfortunate industrial trouble which was being experienced in Britain at the present time. It was a trouble which had given rise to great anxiety in the minds of those responsible for the conduct of industry. British works had been brought practically to a standstill, and had so remained for the past four months. For that reason many prominent industrialists in England had found it impossible to get away at the present time of anxiety, and it was for that reason, and that reason alone, that the number of the members present was not so large as had been hoped. The members had a lively appreciation of the pleasures attendant on a visit to Sweden, and he was certain that had it not been for the reasons he had indicated there would have been a very large attendance of members at the meeting that day.

Sweden had been fortunate from time immemorial in having the keen interest of its ruling Sovereign in the welfare of the industry. He believed that dated back to the time of that great King of Sweden, Gustavus Vasa. The present Sovereign, showing the same deep interest in the welfare of the industry, had extended to the members of the Institute a gracious invitation to meet him that afternoon. It was a disappointment to them that they would not be able to enjoy the pleasure of that reception, but it was a far greater grief to them to know that it had had to be

cancelled owing to the serious illness of Her Majesty the Queen. If it were agreeable to the members, he desired them to permit him to despatch the following telegram :

"To His Majesty King Gustav.—We, the President, Council, and Members of the Iron and Steel Institute, at our Meeting in Stockholm under the auspices of the ancient renowned Jernkontor, desire humbly to express our gratitude for the warm interest in our Meeting which your Majesty has been pleased to manifest by the gracious message from your Majesty communicated to us at our Meeting by Mr. Kjellberg. We beg that your Majesty will consent to accept the expression of our deepest sympathy in your Majesty's present grave anxiety on account of Her Majesty's health.—Rylands, *President*."

In conclusion, he once again thanked Mr. Kjellberg and Mr. Huldt for their very kind reception and welcome.

To the above telegram the following gracious reply was later received and presented by Mr. Kjellberg to the Meeting :

"I wish to express to you and to the Conference my sincere thanks for your kind greetings and my best wishes for a successful work during your interesting meeting.—Gustav."

The Minutes of the previous Meeting, held in London on Thursday and Friday, June 3 and 4, 1926, were taken as read and confirmed.

Ballot.

Mr. H. G. Graves and Dr. A. McCance were appointed scrutineers of the ballot, and on completion of their scrutiny they announced that the following fifty-four candidates for membership and six candidates for associateship had been duly elected.

Members.

Name.	Address.	Proposers.
Adamson, George Ryder	P.O. Box 4, Hyde, Cheshire	J. C. Beeley, H. Adamson, H. Pilling.
Adcock, Frank, M.B.E., B.Sc.	National Physical Laboratory, Teddington	W. Rosenhain, T. E. Rooney, C. H. M. Jenkins.

NAME.	ADDRESS.	PROPOSERS.
Arfwedson, *Bergsingeniör*, Henrik	Ulfshyttan, Sweden	Axel Wahlberg, C. Benedicks, Sir P. Rylands.
Arpi, Ragnar . .	Uddeholms A.B., Hagfors, Sweden	C. Benedicks, Arne Westgren, Axel Wahlberg.
Beijer, Georg Waldemar	Västra Trädgårdsgatan 4, Stockholm	Axel Wahlberg, C. Benedicks, Sir P. Rylands.
Benter, Walter Paul, B.Sc.	37 Elm Street, Midland, Pa., U.S.A.	O. L. Pringle, J. A. Mathews, H. Styri.
Danielson, Nils . .	Hellefors, Sweden	Axel Wahlberg, C. Benedicks, Sir P. Rylands.
Dawson, Horace Cortlandt	Maybourne, Sydenham, S.E. 26	Sir William Larke, K.B.E., H. G. Scott, D. Sillars.
Diedrichs, Axel . .	Uddeholms A.B., Uddeholm, Sweden	A. Herlenius, A. Wahlberg, C. Benedicks.
Ednam, *Viscount*, M.C.	Himley Hall, Dudley, Worcs.	Sir H. Bell, Bart., C.B., Sir R. A. Hadfield, Bart., G. Hatton, C.B.E.
Edwin, Emil . .	Ark Christiesgt. 7, Trondhjem, Norway	Axel Wahlberg, C. Benedicks, Sir P. Rylands.
Enlund, B. D. . .	Strömsnäs Jernverks A.B., Degerfors, Sweden	E. Odelberg, C. Benedicks, A. Wahlberg.
Eriksson, Walfrid .	Avesta, Sweden	A. Wahlberg, C. Benedicks, J. A. Leffler.
Esselius, Eric . .	Jernkontoret, Stockholm 16, Sweden	A. Sjögren, C. H. Carlsson, A. Wahlberg.
Fagerlund, Carl A. V. .	Odinvägen 9, Djursholm, Sweden	R. Nilsson, A. Wahlberg, C. Benedicks.
Fornander, S. G. Edwin	Sandviken Steelworks, Sweden	L. Yngström, A. Wahlberg, C. Benedicks.
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Grabe, Alf. Gerhard .	Jernkontoret, Stockholm 16, Sweden	A. Wahlberg, Sir William Larke, Sir P. Rylands.
Haglund, Ernst . .	Forsbacka, Sweden	A. Sjögren, C. H. Carlsson, A. Wahlberg.
Herlenius, Jonas . .	Uddeholms A.B., Uddeholm, Sweden	A. Herlenius, A. Wahlberg, C. Benedicks.
Hjorth, Olof . .	Hofors, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Horngren, *Consul* Carl Gunnar	Messrs. M. Mansson, Stockholm 16, Sweden	C. Sahlin, A. Wahlberg, C. Benedicks.
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Johansen, Hjalmar .	Kirksgatan 14, Oslo, Norway	A. Wahlberg, C. Benedicks, Sir P. Rylands.
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Kockum, Erik Frans H.	Ronneby, Sweden	B. Kjerrman, A. Wahlberg, C. Benedicks.
Lindberg, Tore . .	Dahlkarlshyttan, Lindesberg, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Lindblom, Samuel Teofil	Sandviken, Sweden	L. Yngström, A. Wahlberg, Sir P. Rylands.
McCloskey, Thomas D. .	1544 Henry W. Oliver Building, Pittsburgh, Pa., U.S.A.	F. C. Fairholme, J. A. Mathews, W. H. Hatfield.
McIntosh, Frederick Fleming, B.S.	Glen Osborne, Sewickley, Penn., U.S.A.	A. Sauveur, J. A. Mathews, F. C. Fairholme.
Marsh, Frank Salton .	Chesterfield Tube Co., Ltd., Chesterfield	F. C. Fairholme, W. H. Hatfield, J. W. Fawcett.
Miller, John . .	Engineer's Office, L. & N.E. Railway, N.E. Area, York	Sir W. Peter Rylands, Sir Hugh Bell, Bart., C.B., Sir R. A. Hadfield, Bart.
Miller, Samuel W. .	Union Carbide & Carbon Research Laboratories, Inc., Thompson Avenue and Manley Street, Long Island City, New York, U.S.A.	F. M. Becket, G. K. Burgess, S. L. Hoyt.
Nishimura, Kojiro .	Kamaishi Mine, Iwate-ken, Japan	K. Tawara, E. B. Westman, F. Dupré.
Palmær, K. W. . .	Sturegatan 60, Stockholm, Sweden	A. Westgren, C. Benedicks, A. Wahlberg.
Pate, George . .	C/o Messrs. D. Napier & Son, Ltd., Acton, W. 3	J. H. S. Dickenson, Cosmo Johns, G. E. Howarth.
Schjelderup, Gunnar .	Christiania Spigerverk, Oslo, Norway	A. Wahlberg, C. Benedicks, Sir P. Rylands.
von Seth, Rutger H. .	Sandviken, Sweden	L. Yngström, A. Wahlberg, C. Benedicks.
Silverstolpe, Helge .	Surahammar, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Ström, Gunnar . .	Finnish Metal Industry Association, Helsingfors, Finland	A. Lindsay von Julin, A. Wahlberg, C. Benedicks.
Sunström, Karl Johan .	Odengaten 92^{III}, Stockholm, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Thalén, Gunnar T. R. .	Sandviken, Sweden	L. Yngström, A. Wahlberg, C. Benedicks.
Tigerschiöld, Kjell Magnus	Fagersta, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Troili, E. P. . .	Uddeholms A.B., Uddeholm, Sweden	A. Herlenius, A. Wahlberg, C. Benedicks.
Wahlberg, Carl . .	Västra Trädgårdsgatan 4, Stockholm, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Wahlfors, William .	Wartsila, Finland	C. H. Desch, W. F. Beardshaw, A. Lindsay von Julin.

Name.	Address.	Proposers.
Westerberg, O.	Strömsnäs Jernverks A.B., Degerfors, Sweden	E. Odelberg, A. Wahlberg, C. Benedicks.
Wettergren, Elis Wilhelm F.	Boxholms A.B., Boxholm, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Wiberg, Frans Martin	Bergskolan, Falun, Sweden	A. Wahlberg, C. Benedicks, Sir P. Rylands.
Wigelius, Nils Thorsten	Hellefors Bruks A.B., Hellefors, Sweden	A. Wahlberg, A. Herlenius, Sir P. Rylands.
Wohrman, Carl Reimar Eugen, S.B. (Hons.)	8 Pierce Hall, Harvard University, Cambridge, Mass., U.S.A.	A. Sauveur, E. L. Reed, J. H. Nead.
Yamagata, Hidesuke	Imperial Steelworks, Yawata, Japan	K. Honda, K. Hasegawa, Sir P. Rylands.
	Associates.	
Bone, Malcolm Drummond, B.Sc., A.R.S.M.	Montrose, Harpenden Road, St. Albans	W. A. Bone, Sir W. Larke, E. C. Evans.
Bradley, Harold, B.Met.	Fullerton Villa, Brinsworth, Rotherham	W. G. Fearnsides, C. H. Desch, R. J. Woodward.
Norgate, Thomas Bladwell	9 Hawcoat Lane, Barrow-in-Furness	E. L. Tosh, W. F. A. Wadham, P. List.
Simons, William Edward	Penylan Court, Cardiff	E. Steer, W. R. Lysaght, C.B.E., D. E. Roberts.
Smith, Bernard Senior, B.Met. (Hons.)	36 Beehive Road, Crookesmoor, Sheffield	C. H. Desch, W. G. Fearnsides, T. F. Russell.
Stanley, Herbert Howard	15 William Street, Frodingham, Lincolnshire	C. H. Desch, T. F. Russell, R. V. Wheeler.

The Secretary submitted, in accordance with Rule 10, the following list of Vice-Presidents and Members of Council due to retire in 1927: *Vice-Presidents:* Mr. F. W. Harbord, Mr. M. Mannaberg, and Colonel Sir W. Charles Wright. *Members of Council:* Mr. H. Brearley, Mr. A. Dreux, Mr. A. Hutchinson, Mr. W. Simons, and Mr. V. B. Stewart.

The President stated that the gentlemen whose names had been read out were eligible for re-election at the Annual Meeting if no other nominations were received within one month of that Meeting.

The following papers were read and discussed:

E. Kinander: "Notes on the History and Organisation of Jernkontoret."

A. Johansson and A. Wahlberg : "The Development of the Swedish Iron Industry during the Last Thirty Years."

W. Petersson : "Notes on the Development of the Swedish Mining Industry during the Last Twenty-Five Years."

C. Benedicks, H. Bäckström, and P. Sederholm : "Anomalies in Heat Conduction, with Some Determinations of Thermal (and Electrical) Conductivity in Iron and Carbon Steels."

A. Lundgren : "The Testing of Hardened Steel."

G. A. Hankins, D. Hanson, and Miss G. W. Ford : "Mechanical Properties of Four Heat-Treated Spring Steels."

A. Johansson and R. von Seth : "The Carburisation and Decarburisation of Iron and Some Investigations on the Surface Decarburisation of Steel."

The following papers were taken as read :

F. Adcock : "The Effect of Nitrogen on Chromium and Some Iron-Chromium Alloys."

J. H. Andrew and H. A. Dickie : "A Physical Investigation into the Cause of Temper Brittleness."

C. Benedicks and R. Sundberg : "Electrochemical Potentials of Carbon and Chromium Steels."

G. F. Comstock : "The Treatment of Steel with Ferro-Carbon-Titanium."

K. Honda : "Is the Direct Change from Austenite to Troostite Theoretically Possible ? "

G. Phragmén : "The Constitution of the Iron-Silicon Alloys."

Votes of Thanks.

The President said that before they parted he desired to take the opportunity of expressing and recording their formal thanks for the many obligations under which they had been placed by their hosts in Stockholm. Such things were very difficult to record, because they were apt to sound formal, when they were really deeply sincere ; and they would have liked to elaborate the point, if it were necessary, to establish that clearly to their hosts. They hoped, however, that the cold words in which their thanks would be recorded would not be regarded as the spirit in which the vote would be passed. The members owed their thanks to so many people that he thought it would be convenient to pass

a resolution in which the Institute recorded its thanks to those to whom they were due. He, therefore, asked the members to join with him in passing the following resolution :

"That a very cordial vote of thanks be accorded to Mr. President Kjellberg, to Mr. Director Kinander, and Members of the Board of Jernkontoret, and to all other Members of the Reception Committee, also to Mr. Axel Wahlberg, and Mr. Grabe, upon whom had fallen the responsibility for the organisation of the programme, for their warm welcome and great hospitality so kindly extended to their visitors, and for all the arrangements so admirably planned and carried out for the entertainment and instruction of the Members whose privilege it has been to take part in the Meeting.

"We also desire to thank the Ladies' Reception Committee, in particular Mrs. Kinander, for their kindness and courtesy to the ladies accompanying the party.

"Our grateful thanks are likewise due to Mr. Huldt, President of the Swedish Society of Civil Engineers and Architects, for his hospitable entertainment.

"We further express our sincere acknowledgments to Mr. Allan Cedarborg, President of the City Council, for the kind hospitality extended to the Members.

"To Mr. Axel Odelberg we owe grateful thanks for his invitation to make an excursion to see his Porcelain Factory.

"Finally, our sincere thanks are due to the Board of the Palace of the Nobility for placing their beautiful rooms at our disposal for the purposes of the Meeting ; to His Excellency the British Minister and Lady Grant Duff, and to Mr. Kershaw, for their kind interest and friendly attentions ; to the Royal Technical University, the Royal School of Mining and Metallurgy, the Government Testing Institute, the Metallographic Institute, and to all Managing Directors and Boards of the Mining and Iron and Steel Companies who will receive the Members at their establishments in the coming week."

He asked the members to pass, with acclamation, that resolution as a very sincere record of their appreciation of the many kindnesses which had been extended to them.

The resolution of thanks was carried with acclamation.

Sir Hugh Bell asked the President to pause before he vacated the Chair in order that the members might perform what was not uncommonly a mere formality, but on the present occasion had a substantial value, as he was sure they would all agree. He invited the members to accord to the President their thanks for the

admirable and autocratic manner in which he had conducted the proceedings of the meeting. A meeting of the kind just held required the firm hand of a President, and that firm hand, covered by the most delicate of velvet gloves, the members had experienced in the Presidential chair. He was sure they would desire to join with him both in the complimentary remarks he had made, and, in so far as the President might so regard them, the critical language of the observations he had made in proposing the vote of thanks.

The resolution was carried with acclamation.

The PRESIDENT said it was very kind of the members to pass the vote of thanks in such a hearty manner, and of Sir Hugh to express those thanks with his usual courtesy and grace. The meeting had certainly not been a difficult one to preside over, and no unruly tendencies had been apparent that required any tyrannical handling from the Chair. The President was at an advantage, which the gentlemen at the back of the hall did not possess, in that he could see the warning hand of time always moving, and could note, therefore, the obligations imposed upon him. The clock had been the real arbiter of their fortunes.

The Proceedings then terminated.

NOTES ON THE HISTORY AND ORGANISATION OF JERNKONTORET.*

By EMIL KINANDER, Director (Stockholm).

Iron-making in Sweden dates from ancient times, and its history is still far from having been completely written. It is, however, not my intention to contribute to historical research, but only to present some short notes about the Institution, the Swedish "Jernkontoret," or, as it should be translated, "The Association of Swedish Ironmasters," at whose invitation this meeting is held in Stockholm, in order to give the honoured guests from the Iron and Steel Institute some general idea of this, as I believe, unique institution.

After emerging from the stage of a domestic industry the Swedish iron industry very early became dependent on the State, and a subject of its special interest. It may be said that the industry was built up on a system of State privileges and concessions. The founder of modern Sweden, Gustavus Vasa, was on the subject of iron-making, as in so many other respects, a far-sighted man. His work was continued by his son Charles IX., the founder of the mining centres in Värmland, and by his grandson Gustavus Adolphus, who, in spite of his numerous and long wars, found ample time to interest himself in the promotion of peaceful enterprise. It was during these times that many foreign ironmasters and workmen immigrated into Sweden, and were received here with a view to improving the making of iron. Many of these foreigners were of that Walloon stock who in later generations proved thrifty, enterprising, and highly skilled workmen.

Under the regency of Axel Oxenstierna, during the infancy of Christina, the daughter of the great monarch, and in the time of her own reign, the iron industry of Sweden gained greatly in strength. Indeed, the first complete ordinance for the mines and ironworks dates from that time, namely, 1649. Throughout the

* Received July 20, 1926.

later part of the seventeenth century the iron industry continued to develop in a marked degree. New blast-furnaces and forges were erected, new or improved arrangements and methods of manufacture were introduced. The increased production was, however, accompanied by a gradually growing uneasiness about the market, and in the last decades of the seventeenth century fears were occasionally expressed lest the price of Swedish iron should fall to an unduly low level. We have records of schemes for the betterment of the impoverished iron trade dating from the last ten years of that century. The most noted of these was one for the formation of an association, an idea which was not new. Such a scheme had already been considered about 1620 in connection with the successful organisation of the so-called Copper Company, called into being practically on account of political conditions, but it had not materialised. In the same manner the first proposal for a scheme for an association of the ironworks likewise failed, as also did a similar project, advanced in the year 1720 by the famous Christoffer Polhem, regarding the sale of Swedish iron through an "iron company," which was intended to free the industry from its dependence on loans from foreign capitalists.

Before two decades had quite passed, however, the question was again under discussion. The making of iron and its export were rapidly increasing; an estimate from about 1745 gives the following figures for the export of bar iron:

1720	about	192,000	skeppund
1725	,,	216,000	,,
1730	,,	245,000	,,
1735	,,	281,000	,,
1739	,,	300,000	,,

It was stated by our Board of Trade in 1738 that about that time the value of the iron export amounted to approximately three-quarters of that of the total exports of the country. But prices were sinking. According to records of 1738 the price current in 1725 of 22 to 24 daler (copper coinage) per skeppund had fallen in 1732 to 16 to 18 daler, and in 1738 it was as low as 13 to 15 daler. Under these conditions complaints concerning the ironworks' tendency to ruin became more frequent.

Amongst the unfavourable circumstances the one which

caused the deepest dissatisfaction was that the iron industry had fallen into the hands of a few men only, who took advantage of the conditions to depress the prices, or at least to impose harsh terms for advances to the ironmasters, and many of these lenders of capital were agents, acting on behalf of foreign merchants.

At the parliamentary session of 1738 the ironmasters gave vent to their fears in several ways. By agreement of the parliament a general meeting of ironmasters—the origin of the "Parliament of Ironmasters" (*Bruksriksdag*)—was held in one of the chambers of the parliamentary committees, where they had the opportunity of formulating their grievances. Further, there were submitted by private persons to the "secret parliamentary commission" two projects for establishing an Iron Company or an Ironmasters' Association. However, the Secret Commission rejected the proposal for such an Association, and preferred to continue the policy inaugurated already in 1735, which was to permit the bank to grant loans against iron on the wharfs as security. The limit for the loans was increased from three-quarters to seven-eighths of the value of the iron. At the same time bank loans on real estate belonging to the iron industry were facilitated. At the next parliamentary session this policy was continued by lowering the interest for such loans. At the parliamentary session 1742 to 1743 the concern on account of the position of the iron industry had increased, in view of the falling off in exports. The exports, in 1739 about 300,000 skeppund, had in 1742 fallen to only 229,000. The question was seriously debated inside as well as outside Parliament, and opinions differed as to the expediency of such an Association.

The commercial agent Andreas Backmansson, ennobled in 1743 under the name Nordencrantz, is regarded as the founder of Jernkontoret. In that year he submitted to the Secret Commission a memorandum on the iron industry, and after preliminary discussions between him and the so-called "Iron Commission," consisting of three State councillors and three works owners, the Board of Trade was ordered to arrange that for every iron district, or *bergslag*, the owners of the forges within its boundaries should elect one or two delegates to meet in Stockholm in the beginning of 1744 to decide "on all such matters

that should be necessary for the preservation of the interests of the iron districts and the interests of the realm depending thereon."

This new "Ironmasters' Parliament" or *Bruksriksdag*, consisting of about forty delegates from the iron districts, assembled in the capital in the beginning of 1744 and entered into negotiations with the previously mentioned "Iron Commission," for which purpose the delegates from amongst themselves selected twelve deputies. The negotiations ended on March 17, 1744, and resulted in an "*agreement between all works owners*" being accepted "for further discussion and approval by their colleagues at home." This agreement may be regarded as Jernkontoret's earliest charter of foundation, from which the leading features may be quoted.

Certain minimum prices were determined for the sale of the different kinds of iron. In order to maintain the level of those prices the ironmasters agreed to establish an association, with headquarters at Stockholm and directed by certain delegates, which association was to buy all iron that could not be placed on the market at acceptable prices, and hold it until it could be advantageously sold. In order to ensure the necessary funds, each ironmaster was to pay one daler, copper coinage, for each skeppund of iron manufactured, one-half in May and one-half in September, and further, during the first years of the Association's existence, to allow three daler (copper coinage) to remain with the Association for each skeppund of iron sold to it.

The agreement, which was signed by thirty-two owners of works, was to be valid for three years. Until the expiration of that period the works owners themselves, or their deputies, should meet yearly every 1st of May for the audit of the accounts, for the fixing of the selling-price of the iron for the year, of the dues of the Association, and for decisions on other matters concerning the Association. Provisionally, seven delegates were appointed for one year, Nordencrantz being one, and simultaneously rules were adopted for the delegates' management of the Association. According to these rules only three of the delegates were to be "within" the Association, that is, having executive powers, while the other four were practically only advisers.

The time immediately following this agreement was chiefly occupied in efforts to increase the number of associated works.

Several difficulties were encountered, above all in procuring the capital necessary for the first purchases of iron.

According to a decision at a meeting in February 1747 a large number of ironmasters met in Stockholm in the autumn of that year at the opening of the parliamentary session, and renewed their appeal to the Government for aid to the iron industry. The whole question was referred to the Secret Commission of the Parliament, where it was taken charge of by the deputies for commerce and manufacture, amongst whom were the Secretary of State, C. G. Löwenhjelm, and Councillor Lars Benzelstierna of the Board of Mines and Ironworks, who had both been strongly active in establishing the Association; also the influential Commercial Councillor Thomas Plomgren, a merchant highly interested in the iron trade. The economic basis having been established by the lowering of the interest of the State Bank to 4 per cent. for loans against iron as security, and by a special ordinance against over-production, Plomgren personally worked out a memorandum "regarding the establishment of an Association of Ironmasters" (*Jernkontor*), which was approved by the above-mentioned deputies and by the Secret Commission on December 3. On December 29 it was sanctioned by the King and issued as "Official Rules for Jernkontoret."

The Royal ordinance of December 29, 1747, mentions as the chief motive for establishing the Association of Ironmasters, in accordance with the earlier projects, the necessity of extricating the iron trade from the grip of foreign capitalists and their influence on the prices. The Association would step in and with the aid of its funds save Swedish sellers of iron from the necessity of selling their goods at an unfavourable time and at too low prices. This aim was to be achieved by granting the seller the right to obtain loans from the State Bank against iron as soon as it was weighed and accepted at the wharfs up to seven-eighths of its value and at only 4 per cent. interest. What he had thus paid as interest to the bank, he was entitled to have refunded without delay from Jernkontoret. In order to procure the necessary funds for the Association, the *buyer*—not the *seller*, as previously determined—had to pay to the Association one daler, copper coinage, for each skeppund of bar iron bought.

If necessary for bettering or regulating the prices, the Association should itself appear as buyer.

Regarding Jernkontoret's administration the Royal ordinance prescribed that the executive delegates should be four in number, elected by the works owners for three years at a time, and that the accounts should each year be audited by deputies elected by the works owners.

At the beginning of 1748 Jernkontoret was therefore in a position to start work. The first period was one of lively activity, both internally and outwardly. Internally it was necessary to work out in detail the organisation of the new institution, externally to trace out and improve the plans for the attainment of the object—namely, the benefit of the Swedish iron industry.

According to the agreement of 1744, the executive powers were chiefly in the hands of the three delegates "within the Association." These were in 1747 the before-mentioned Löwenhjelm, the works owner J. H. Lefebure, and the *Bergmästare* Erik Stockenström, all three of whom joined the new board. The fourth seat was occupied from 1748 by the Commercial Councillor Thomas Plomgren.

Regarding the organisation of the work, it was soon found necessary to revise the somewhat provisional rules of 1744, and after careful preparation new rules for the appointment and duties of delegates and of the "revising deputies" were accepted at a meeting of the works owners in 1751. For the election of delegates the works owners were to meet every third year, while the deputies, whose number was raised to twelve, elected by the works owners in the different districts on the basis of the quantity of bar iron "introduced into the Association," were to meet yearly. The rules also contained minute instructions as to the lines of activity of the Association and of the deputies. As characteristic of those times it should be mentioned that for economic reasons the administration in general was surrounded by strict secrecy, and an oath of silence was imposed on the delegates, the employees, and the deputies.

According to the rules of 1751, the main function of the delegates was, as originally stated, the regulation of the iron trade as far as possible in order to maintain the prices of Swedish

bar iron at a proper level. For this purpose it was the duty of the delegates every year to fix reasonable prices according to the various kinds of iron and the different markets. Two of the delegates were commissioned to visit yearly the market at Kristinehamn, and other markets to see to the application of these prices. For a long succession of years the journey to Kristinehamn and the attendance at that big iron market at the end of February were the chief actions taken by the delegates in the performance of their duty, and as the prices of this market were considered to be the basis for the iron market throughout the country, visits to other markets were generally omitted.

Within the first years of Jernkontoret's existence, new forms of support to the iron industry had already begun to appear. The rules of 1751 permitted that the funds of the Association, as far as they were not immediately needed, could be deposited in the Bank or utilised for the granting of loans to private persons against certain kinds of securities. Thus commenced Jernkontoret's *lending functions*, which thereafter continued and still continue.

But it soon became apparent that reasonable selling prices and cheap loans were not sufficient. It was found that the technical side of iron-making also was in need of development, and thus the question of Jernkontoret's *technical mission* became prominent.

At the revision meeting in 1749 the deputies raised this question, and especially dwelt on the importance of increasing their knowledge as to the position of the foreign iron industry in different respects, and the works owners meeting in 1751 set aside a yearly sum for this purpose. In the rules a special paragraph was inserted about "collection of knowledge" as one of Jernkontoret's purposes. This was the beginning of the "*travelling grants*." In this connection the question was raised of procuring models of machinery and plans suitable for the iron industry, and the delegates were charged to work in this direction.

Likewise the importance of improved methods for charcoal burning, blast-furnace practice, and other branches of iron-making was noted. Any plans for improvements should be communicated to the Association, which was to support new

experiments. Above all, attention was directed towards improvement in blast-furnace practice, and the works owners' meeting in 1751 granted means for employing for a trial period of three years a *chief smelting-master*, who should undertake necessary experiments in this respect. In the same year the first occupier of this position was appointed, namely, the inspector of mines, Sven Rinman, who thereupon commenced the exceedingly important work in Jernkontoret's service which he later continued with so much success. The charge was considered so important that it not only became permanent, but in the year 1755 another similar post was created, followed in 1757 by a third, in 1760 by a fourth, and in 1761 by a fifth, specially for Finland. As early as 1757 the smelting-masters had been provided with assistants, young men to be educated in the trade (*ämnessvenner*). In many other respects during its first period of existence Jernkontoret assisted technical advancement in such matters as ore finding, research on charcoal burning, pumping, and mining of ore.

Originally Jernkontoret, as will be noted, was intended exclusively for the support of the bar iron trade. But by the granting of assistance in 1749 to a manufacturer of finished iron goods, the question of affiliating all such manufacturers with the Association was soon brought to the fore. By the Royal Ordinance of September 22, 1752, it was allowed as a temporary measure and by way of experiment that certain manufacturers of heavier finished iron ware should be admitted to the Association against special dues. The question of continuing support to all such manufacturers was again raised at the parliamentary session in 1755–1756 and was summarised by the Secret Commission in a detailed memorandum, which by Royal Ordinance dated December 10, 1756, January 31, and February 1, 1757, was communicated to Jernkontoret for its guidance. This memorandum related to improved manufacture as well as to facilitating the sale of the goods. In the former respect there were prescribed certain measures intended to ensure suitable raw material. Just as the chief smelting-masters were to work for the production of good pig-iron, two "*directors for the iron and steel manufactures*" were appointed in 1753 to supervise and improve the working up of the pig-iron into

suitable raw material for these manufactures. One of these directors dealt with questions relating to the finer iron and steel wares, the other with the coarser manufactures, the so-called black forgings. The directors were in case of need entitled to make arrangements for the payment from Jernkontoret's funds of premiums for the manufacture of such raw material, for tests, &c. In order to facilitate the selling of the goods, export bounties were introduced, which were also to be paid by Jernkontoret. The cost of these arrangements was to be covered by a yearly sum of 30,000 daler, copper coinage, granted by Jernkontoret, by the saving obtained through the reduction in 1756 of the bank interest from 4 to 3 per cent. on loans on iron granted to Jernkontoret, and finally by a tax on bar iron exported on foreign ships, so called "licence dues," imposed in the same year. From 1763 separate accounts of all these funds were kept by Jernkontoret (the "licence-fund"). According to a decision in 1756, certain additional kinds of coarser wares could be introduced into Jernkontoret with the right for the Association to obtain certain dues. Separate accounts of these funds, and the dealings with them, were kept from 1756 under the title "The Iron Manufacture Fund."

In 1757 these extensive changes in Jernkontoret's activity were applied. The first director of black forgings was Reinhold Angerstein, a man highly distinguished in the Swedish iron industry and celebrated for his extensive journeys to foreign countries. His travel descriptions contain very valuable information regarding the iron industry in most European countries and are kept in manuscript at Jernkontoret. At his death in 1760 Sven Rinman became his successor and remained in this position for thirty-two years, which fully shows the great importance of this charge. The first director for the finer iron manufacture was Samuel Schröder.

The increased membership of owners of manufacturing works in the Association gave them the right to elect one deputy, and caused an increase in the number of delegates from four to five. According to Royal Ordinance of July 27, 1762, this fifth delegate was to be elected by the owners of the manufacturing works.

The establishment of Jernkontoret in 1747 was in full harmony with the protectionist policy of the political party, the "Hats,"

then reigning. The decline of this policy about 1760 had a great influence on Jernkontoret, and when the rival party, the "Caps," at the parliamentary session 1765 to 1766 came into power, Jernkontoret became the subject of rather severe criticism, which culminated in new rules, worked out by the Secret Commission and signed by the King on October 21, 1766, containing considerable restrictions on its self-government, especially with regard to the election of the executive delegates. These rules, however, were in force for only a short time. After the political change which came about in 1768 they were replaced in 1769 by new rules, established by the works owners themselves, with new instructions for the delegates.

The rules of 1769, which for a long time directed the activity of Jernkontoret, practically coincided with the rules of 1766, except in the one respect that the former strict secrecy regarding the administration was abolished. In other respects the new rules chiefly consisted of a codifying of the practice followed during the earlier period.

The meetings of the part-owners of Jernkontoret, already for some time called *Brukssocieteten* (the Society of Works Owners) were to be held every third year, but the audit was to be made every year by deputies, elected in the different iron districts (*bergslag*) of the country. The delegates or members of the board were limited to five, and the society was to elect those "in whom they had most confidence."

The rule was maintained that the dues to the Association from the bar ironworks, forges, and the manufacturing works should be paid by the buyer, for the reasons previously stated.

The chief object of Jernkontoret's activity was considered to be the support of works owners in need, and of manufacturers of steel- and black-forgings, by means of loans in order to relieve them from the hard conditions under which capital otherwise had to be borrowed. For this purpose the Association sent yearly to the market at Kristinehamn a sufficiently large sum of money for loans, and likewise kept funds at disposal in other iron markets. In general loans were granted, but in case of need, purchase of iron could be resorted to. Loans to private works owners were permitted and other kinds of benefits were granted

to the different branches of the iron industry—ore finding, mining, mechanics, charcoal making, blast-furnace practice, means of transportation, &c.—which might be found of importance. The fund for export bounties was administered separately for its purpose, and in case of a surplus this might be applied in other ways for the benefit of the manufacturing works.

As already mentioned, simultaneously with the new rules the Society of Works Owners laid down new instructions for the delegates or the board of directors. These instructions, dated November 8, 1769, dealt more especially with the lending business, and set forth three different principal forms which had gradually been developed. The ability to lend was increased by a credit granted to Jernkontoret by decision of the parliamentary session in 1769, amounting to ten barrels of gold, for use until the next parliamentary session.

Through the rules and regulations of 1769 mentioned above, the independent position of the Association towards Parliament and other parties had been completely recognised. The part-owners and the delegates were able to conduct the administration according to their own conception of what at different times might be needed to promote the aims of the Association.

Jernkontoret's activity is nowadays conducted on practically the same lines as were laid down during the first period of its existence. Changes indeed occurred due to different conditions at different times, but in general these were of no great consequence. However, Jernkontoret has gradually developed and strengthened its leading position in the iron industry. Consequently, a detailed description of the work performed would in many respects be identical with an enumeration of most of the important changes in our iron industry from the latter half of the eighteenth century until the present day. This necessarily falls outside the scope of this summary, which must be limited to a short statement of certain more important dates and facts during the development besides tracing the outlines of Jernkontoret's present activity.

As already mentioned, the rules of 1769 remained the chief foundation for Jernkontoret's work, though successively supplemented by instructions given by the Society of Works Owners at their general meetings. These "accounts of decisions by the

Society of Works Owners" have been regularly printed since the year 1805.

New and more comprehensive rules were not issued until 1868. This happened in connection with certain proposals in the middle of the nineteenth century to reorganise the Association. In 1841 it was proposed to establish within Jernkontoret a "private bank for works owners"—a project that did not, however, meet with approval at the general meeting in 1842. About 1860 the question of reorganisation was again raised, now in the form of a proposal that shares should be issued to the partners and that dividends be paid yearly, but this proposal also was rejected by the Society. During the debate on the matter, however, a committee was formed for drawing up new rules, and at an extraordinary meeting in June 1867 the Society accepted these new rules, which on May 20, 1868, at the request of the society, were sanctioned by the King.

The general object of Jernkontoret's activity was, however, not altered. The words used in the new rules to express this object, that Jernkontoret should: "Through loans to the members of the society, through grants or other kinds of support to scientific or technical research, as the society might decide, support and promote the iron industry," might just as well have been used as a summary of its aims a hundred years earlier, and this expression, which in later revisions of the rules has remained practically unchanged, is to this day a good and adequate definition of Jernkontoret's aims and activity.

The right of part-ownership in Jernkontoret had, on the other hand, after 1769, necessarily undergone some changes. The loss of Finland in 1809 occasioned the secession of the Finnish works owners. A large number of new works being desirous of joining the Association it was determined at the meeting in 1805 that new bar-iron forges might be admitted on payment of certain dues, determined by the old part-owners and in proportion to the quantity of bar-iron manufactured. Similar terms were agreed on for new works manufacturing finished iron.

A novelty regarding part-ownership was introduced in 1918, when through a resolution of the Society of Works Owners, sanctioned by the King on October 4 of the same year, right of admission was granted to works which manufactured exclusively

pig-iron, so-called pig-iron furnaces. It was determined that rights and dues should be calculated on the basis of 2 centners of pig-iron corresponding to 1 centner of bar-iron. A simultaneous proposal to extend the right of part-ownership also to iron mines did not meet with approval. In connection with this extension to include the pig-iron manufacturers, the chairman of the board, then Major-General G. Geijer, put forward a proposal to the part-owners to increase their parts, with the result that the part-ownership of Jernkontoret was increased by about 300,000 centners, corresponding to an entrance due of about 1,500,000 kronor. This large increase of Jernkontoret's capital, effected under exceptionally favourable circumstances for the iron industry, made it possible for Jernkontoret to meet the considerably increased costs of the period of crisis without noticeable decrease in its activity.

Regarding the more formal characteristics of Jernkontoret as an institution, the rules contain the following fundamental paragraphs. "Owners of Jernkontoret are those ironworks and blast-furnaces which are introduced as part-owners," "Part ownership by the works or the blast-furnaces is proportionate to the number of centners of forged iron introduced," and finally that "part-ownership or part thereof cannot be withdrawn from the Association." From this it follows that the only way for a works that has been shut down to utilise part-ownership is to transfer such part-ownership to an ironworks actually running. It is this strong accentuation of the iron trade itself as owner of Jernkontoret and the consequent exclusion of purely personal factors that has been the most important factor in Jernkontoret's ability to exist and to fulfil its aims for nearly two centuries.

Part-ownership in Jernkontoret was originally determined according to the average output of forged iron during the previous three years. This relationship between quantity forged and the dues to Jernkontoret ceased, however, to exist when the quantities of iron forged grew, because the cost of "introducing" new iron—that is, increasing the part-ownership—became too great. The entrance fee per centner is fixed at four-fifths of the sum obtained by dividing Jernkontoret's reserved capital by the number of centners of iron already introduced. Exception to this was made in the case of the above-named large increase of

part-ownership during the war. These circumstances did not however, exclude changes in the part-ownership, but such changes have generally consisted in transferring part-ownership from a shut-down works to an active works, a provision which has sometimes been taken advantage of to a considerable extent. Changes have further occurred, although more rarely, through setting off the value of the part-ownership against debt to Jernkontoret, according to conditions in the rules.

The distribution of the part-ownership amongst the works owners is shown below.

Part-Ownership. Centners.	Number of Owners.	Total Part Ownership. Centners.
More than 100,000	2	436,116·31
50,000–100,000	6	344,587·96
25,000–50,000	8	266,213·31
10,000–25,000	21	352,369·12
5,000–10,000	25	174,026·55
Less than 5,000	86	176,588·22
Total number of part owners .	148	Total 1,749,901·47

It consequently appears that the part-owners of Jernkontoret at present are about 150, and that the parts owned by the greater number of these are below 5000 centners.

In voting at the meetings of the Society one vote is allowed for every centner, but the number of votes allowed to any one part-owner may not exceed 1000.

Regarding the composition of the board, it should be observed that, according to a decision of the Society in 1842, two vice-delegates could be elected in addition to the five delegates constituting the board, to be called into service when wanted. In 1856 it was determined that besides the five delegates and two vice-delegates there should also for each period of three years be elected an equal number of extraordinary delegates and an equal number of vice-delegates for them. These extraordinary delegates were to be called in at so-called " plenary sittings " where certain more important questions were under consideration. The rules of 1868 contained these stipulations, and when in 1894 yearly meetings were introduced, the three-year period of service was

adhered to, with the exception that the two vice-delegates for the regular delegates were elected for one year only.

The number of deputies or revisers has undergone several changes. The highest it has reached is nineteen. In connection with the revision of the rules in 1894 it was determined that at each revision the number of deputies should be nine, each elected, together with one vice-deputy, for and by the works owners in certain districts. This arrangement is still in force.

The rule that the general meeting of the Society should be held every third year was long valid, but for different reasons extra meetings were held on numerous occasions. Towards the end of the eighties strong claims for yearly meetings were advanced. A proposal to this end was rejected in 1889, but it occasioned the appointment of a committee for considering the necessity of changes in the rules of the Association. This committee's recommendation to hold yearly meetings was accepted by the Association in 1892 and 1893, and was on January 26, 1894, sanctioned by the King. General Meetings are now held in May or June every year, and extraordinary meetings when decided upon by the Society or by Jernkontoret's board of directors. Since 1868 it has been the rule that on demand of representatives of not less than one-tenth of the iron introduced, the board must issue a summons for an extraordinary meeting. Since 1894 extraordinary meetings have been held in 1898, 1901, 1909, and in 1926.

Since the earliest days of the Association there have been discussed at meetings not only questions regarding the revision and the organisation, but all kinds of general questions and proposals relating to the advancement of the iron industry. Private persons are also allowed to raise such questions within a certain specified time. Such proposals before being submitted to the meeting shall be accompanied by a report from the board of directors and from the deputies. The latter are also to report on propositions made by the board of directors. Changes in the rules shall be approved at two consecutive meetings, and according to the rules of 1894 a certain qualified majority is required at the second meeting to confirm such a change.

Since the latter part of the nineteenth century there have been arranged, in connection with the general meetings, *technical*

meetings for discussion of questions of interest for the iron industry, generally called "Jernkontoret's technical meetings."

In 1853 it was decided at the next general meeting, in 1856, to hold a meeting for discussion of certain previously announced questions, in which everybody interested in iron-making was invited to partake. This was repeated every third-year meeting until and including 1880. From that time they took place at irregular intervals, discussions being held in the years 1886, 1892, 1895, and 1899. From 1902 they were resumed at every meeting, and are now held every year.

The rules of 1901 leave it to the board to decide whether such discussions should be held at the next meeting of the Society, and to make the necessary arrangements. However, in later years it has been the practice for the Society to elect yearly a chairman with his deputy for the next discussion, and the committee, previously elected yearly by the board, is now a permanent committee supplemented only when necessary. These technical discussions, the minutes of which are published in *Jernkontorets Annaler*, apart from their purely technical importance, have proved of considerable value in affording opportunity for the technical staffs of the iron and steel works to meet for discussion and fraternisation.

It has already been mentioned that Jernkontoret's activity during the first period of development was directed on two principal lines: direct loans to works owners in need and support to institutions of importance for the iron industry. These two principal lines were also accentuated in the rules of 1769, 1868, and 1894, mentioned above.

Regarding the practical application of these rules the journeys to the "Fastingen" market at Kristinehamn had been one of the principal forms for Jernkontoret's support to works owners desiring assistance. Direct purchases of iron by Jernkontoret seem to have occurred for the last time in 1780. In 1808 it was, however, decided by the Society that until the next meeting the journeys to Kristinehamn should be discontinued, and at this meeting in 1811 their cessation for the future was decided. Sporadically such journeys have, however, occurred later.

When these journeys ceased, the form of direct loans had already long become the principal method for supporting works

owners. The conditions for such loans in the rules of 1769, previously briefly referred to, have later undergone changes from time to time. At present they are as follows.

Those special loans which owners of works, admitted to Jernkontoret, in virtue of the part-ownership, are entitled to obtain are "*advance loans*" and *building loans*. Advance loans against approved security may be granted to an amount of 5 kronor for each centner of iron for which the works is part-owner in Jernkontoret. The interest is now 4½ per cent., and the loans are repayable either after certain fixed periods, not exceeding twelve months, or after notice, not exceeding three months. They may, however, be renewed on falling due.

Building loans are granted, likewise against security approved by the board, to an amount representing at most half the cost of the building in question, but not exceeding 100,000 kronor for each part-owner. Interest on such loans shall be paid at 6 per cent. per annum. The loan shall be repaid in equal instalments, not less than one-fifth every year, commencing the year after that in which the building shall have been completed. The total shall, however, be repaid not later than eight years after the loan is granted. The amount of building loans may in no instance exceed 1,000,000 kronor.

To be entitled to obtain such loans, the stipulated dues, 2½ öre yearly for each centner of iron introduced, must be duly paid. In addition to the above privileged loans a part-owner in Jernkontoret is entitled to obtain further loans against approved security to such extent as Jernkontoret's means may allow and at an interest which during recent years has been fixed at ½ per cent. lower than ordinary bank interest.

Jernkontoret's other funds must be invested according to conditions laid down by the Society.

The financial possibilities of Jernkontoret were, as previously stated, during its first period of existence dependent on the right of the works owners to obtain bank loans against iron as security. When this right during the crisis about 1765 had temporarily been annulled, Jernkontoret obtained a credit with the bank for ten barrels of gold, and although the right to loans against iron had been revived in 1770, Jernkontoret during the last decade of that century still remained in a position to use this

credit, as well as new credits granted by the parliament in 1778 and 1786.

During the early years of the nineteenth century a new crisis occurred which especially afflicted the iron industry. On this occasion, too, the State came to its aid. After debates in the parliamentary sessions in 1812 and 1815, Parliament in 1817 to 1818 put at Jernkontoret's disposal "for the advantage and benefit of the iron industry" a new credit of 600,000 riksdaler banco with the stipulation that the surplus revenue arising from the difference between the interest obtained and paid, should be used for new experiments of value to the iron industry. Special rules were issued for the use of this so-called "credit fund" of Jernkontoret, and separate accounts of these funds were kept. Credit to the same amount was granted until 1869, when it was lowered from 900,000 to 750,000 kronor, and it ceased completely with the year 1870. During the years immediately following Jernkontoret obtained, however, an ordinary credit from the State bank, though for a smaller amount.

Apart from the purchase of iron and direct loans there was, as mentioned above, at the disposal of Jernkontoret a special fund called "the licence fund," out of which were paid export bounties on the sale to foreign countries of manufactured goods. This branch of activity was, however, concluded in 1824, when the fund on Jernkontoret's request by decision of the King was delivered over to the Board of Trade, the export bounties having ceased in 1820.

The policy of engaging prominent men for the technical advancement and control of the iron industry which Jernkontoret had adopted during the first decades of its existence, together with the purchases of iron, direct loans, and export bounties, was naturally still further developed when the Association in 1769 had gained its independence.

During the first period of Jernkontoret's development two departments of great importance had already been organised, represented by *the five chief smelters* and *the two directors of the iron and steel manufactures*. At the end of the eighteenth century three new similar posts were created, namely, a *director of bar-iron making* in 1778, a *mechanic for mines and iron-works* first appointed in 1779, and a *director of pig-iron making*, to which last post in

1780 one of the chief smelters was appointed, an arrangement which, however, temporarily ceased in 1790. Like the chief smelters and the two first directors these three new officials were appointed by the Board of Trade, or in certain cases by the King, but their salary was paid by Jernkontoret, and they consequently owed their position in the first instance to Jernkontoret.

In 1805 a more stable arrangement of the technical staff was brought about, especially regarding pig-iron smelting, through combining the inspection of the making of pig-iron with that of bar-iron forging. To this end one of the chief smelters was elected director of pig-iron smelting and bar-iron forging. The chief smelters' organisation according to the decision of 1805 consisted of four chief smelters, each having a special district, one of them being director, four assistants (*ämnessvenner*), one for each district, and besides these, students, foremen, and builders. In 1817 we find Jernkontoret's "mechanical staff" organised with one "master mechanic" as chief, three mechanical assistants, and five works builders.

In 1823 the organisation of the technical staffs came under consideration, and a special committee was appointed to report on this question. In accordance with this report it was decided in 1826 to organise a new technical staff, the so-called "chief inspection of bar-iron making," which should consist of two chief inspectors or directors of bar-iron making, each of whom should have the right to engage two skilled master forgemen as assistants.

Amongst the decisions at the meeting in 1826 is to be noted that whereby the Society adopted the opinion expressed by Jernkontoret's board and the district deputies that "at present more was to be gained through a fund for rewarding skilled men than through fixed salaries for an increased number of employees," and consequently a yearly sum of 1500 riksdaler banco was put at the disposal of the board for "rewards to persons who in some distinguished manner had promoted the iron industry or whose services were needed for the same."

At the general meeting in 1838 it was decided to leave vacant the position of director of pig-iron smelting and bar-iron making, and to make some changes in the chief smelters' and mechanical staffs, amongst others to replace the students by stipendiaries. The above-mentioned sum for rewards was increased from 1500

to 5000 riksdaler banco, and its purpose was in some degree extended. In 1853 the sum was further increased to 6666 riksdaler and 32 shillings banco.

In 1856 the Society resolved that the position as director of pig-iron smelting and bar-iron making, vacant since 1838, should again be filled under the new designation, "chief director of Jernkontoret's external staffs," and Knut Styffe, chief director and dean of the Royal Technical Institute, was elected to this new position. The latter, however, declined the position and it was left vacant, and abolished in 1862.

Again in 1856 the Society approved a proposed arrangement to unite the chief smelters and the chief bar-iron inspection staffs into one, to be called the metallurgical staff, consisting of six directors, six stipendiaries, students and foremen as required. This arrangement was put into practice in 1859.

When the question regarding the technical staffs in 1865 again was considered by the Society, the opinion was declared that the organisation of the "external staffs"—that is, the metallurgical and the mechanical—could not be considered modern and adequate, and that the iron industry was in need of additional scientific and technical assistance which should be supplied by Jernkontoret. Consequently it was resolved that the "external staffs" should be withdrawn. In their place a new staff was to be organised which should bear the name "Jernkontoret's bergsstat," and consist of the teachers of the technical schools supported by Jernkontoret, and of other persons appointed by the Society. The grant for technical purposes, which had in 1856 been raised to 8000 riksdaler banco, was in 1865 again raised to 18,000 riksdaler riksmynt.

The proposed new staff was further debated by the Society in 1867, when no decision was arrived at, and again in 1871, when the Society decided that it should not be organised.

The board declared that the need of Jernkontoret and its part-owners for technical assistance was for the time being adequately met, as a number of the officials from the former staffs were still active, and as the board had means at its disposal from the yearly grant of 18,000 riksdaler for engaging new qualified men. The question of the technical staff remained in this position during many years, from 1871 to 1903. The grant for such purposes

Jonas Carlsson Kjellberg,
President of Jernkontoret, 1926.

The Brinell Medal
(Struck in celebration of his 75th birthday).

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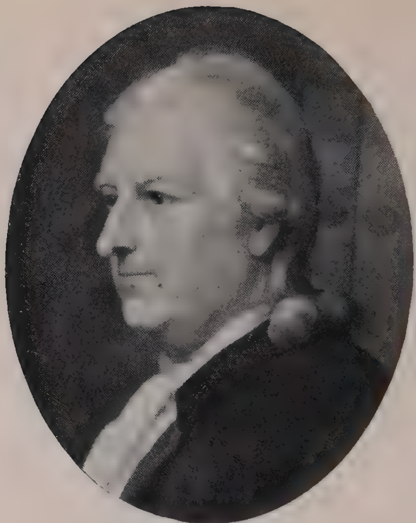
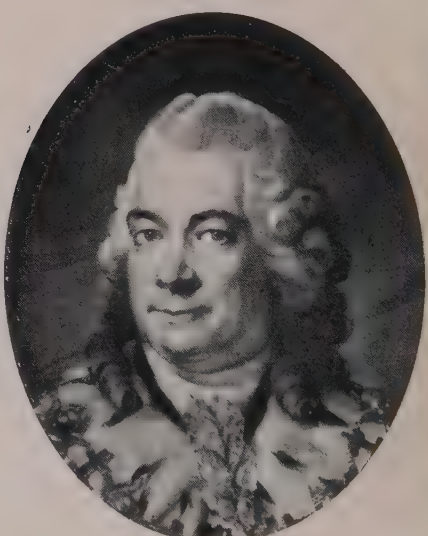


Baron Andreas Nordenkrantz

Carl Gustav Löwenhjelm.



Eric von Stockenström.

Thomas Plomgren.

Reinhold Angerstein.

Richard Åkerman.

PLATE IV.

The House of Jernkontoret.

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was in 1886 increased to 22,000, in 1896 to 25,000, and in 1897 to 30,000 kronor. At the request of the board additional grants were made by the Society for engaging prominent technical men.

In 1902 the question was raised regarding new arrangements of Jernkontoret's technical staff, and a committee was appointed to consider the matter. The principal question, whether a technical staff was still needed and useful to the Swedish iron industry, was answered by this committee to the effect that as far as they understood the matter, the opinion that such was the case could scarcely be disputed. The committee reports on this subject: "The circumstances have in this respect certainly changed in that the works owner exerts himself more than previously, and in order to hold his own in competition, he must seek to engage the best obtainable technical men. On the other hand, the technical questions have grown in extent, and they vary to such a degree, that the industry rarely if ever can by itself find a sufficient supply of men qualified in all branches. It may further often be difficult for the engineers to follow developments closely enough and to utilise them advantageously. Under these circumstances it is desirable that Jernkontoret shall undertake in the future to serve its part-owners in this respect."

As to the manner of meeting the requirements, the committee endorsed the opinion already expressed on different occasions regarding the unsuitability of a fixed staff of technical officials, and recommended that technical experts should be engaged only in so far as especially able men could be obtained for the more important branches of the industry. The committee, however, also discussed the question of the then existing need of experts. The report recommends as most desirable the realisation of the plan approved by the Society in 1856, but at that time not carried out, to appoint a chief of Jernkontoret's technical staff. The committee considered it highly desirable that Jernkontoret should engage some person of especially prominent technical ability and practical experience capable of uniting all the technical experts within Jernkontoret. He should further follow technical progress, act as technical adviser to the board, and if possible also as expert on questions regarding iron and steel. For this official was suggested the title Chief Engineer.

After consideration of this report by the Society in 1903, the following decision was arrived at:

Without organising a permanent staff of technical experts, there should be attached to Jernkontoret until further notice, and provided suitable persons can be found, one chief engineer, two metallurgical engineers, two mechanical engineers (among which five engineers at least one should be expert in questions regarding combustion), one mining engineer, one expert on peat, and three master forgemen, together with a suitable number of stipendiaries. The experts should principally serve the members of the Society and the board of Jernkontoret as advisers. A sum of 70,000 kronor was granted for:

(*a*) Salaries to those who, according to contract, are engaged as engineers, master forgemen, or as technical assistants of other kinds to act as advisers to the members of the Society or Jernkontoret's board.
(*b*) Scholarships to young men who, after training in technical schools or in other ways, have gained technical education in the iron industry, and apply themselves to metallurgy, mechanics, or mining.
(*c*) Travelling scholarships, and
(*d*) Prizes to persons who, whether they obtain salaries from Jernkontoret or not, have distinguished themselves through useful inventions or other practical activity in the iron industry.

Of the sum of 70,000 kronor granted, 55,000 kronor were estimated as salaries for technical experts, the chief engineer included, and master forgemen, 6000 kronor for stipendiaries (holders of scholarships), 6000 kronor for travelling scholarships, and the remaining 3000 kronor for sundries.

As first holder of the new position of chief engineer at Jernkontoret was chosen the chief engineer of the Fagersta Steel Works, J. A. Brinell, who through his discoveries and authorship had gained a reputation as one of the foremost amongst the metallurgists of the time. He entered his position in 1903 and remained in Jerkontoret's service till 1914, when he retired on a pension. He was succeeded by A. Wahlberg, also previously chief engineer at Fagersta. Brinell died in 1925.

Since 1903 that branch of Jernkontoret's activity which is dependent on the above-mentioned grant "for engineers, master forgemen, stipendiaries, for travelling scholarships and prizes" has continued chiefly along the lines then prescribed. To the experts belonging to Jernkontoret's regular staff there have been added other experts who have engaged themselves to assist Jernkontoret and its part-owners, in return for certain remuneration, to such an extent as may be possible with regard to their chief occupation. Amongst these are some of the professors at the Royal School of Mines and Metallurgy in Stockholm. The sum granted has varied according as changes in the staff also have occurred. In Jernkontoret's budget for 1927 it is fixed at 81,000 kronor, additional expenditure incurred on account of the crisis not included. Of the fixed sum at present only 65,000 kronor are estimated for experts, including the chief engineer and master forgemen, 6000 kronor for stipendiaries, 8000 kronor for travelling scholarships, of which sum 2000 kronor are intended for foremen and workmen, and finally 2000 kronor for prizes. In addition to the large sum of 81,000 kronor a further grant of 2000 kronor has been contributed to the cost of a laboratory for Jernkontoret's expert on charcoal.

Amongst the items of the large grant those for stipendiaries and travelling scholarships should especially be noted. The former includes six yearly scholarships of 1000 kronor for young men who have recently finished their technical school training; they are intended as a support during their practical training in the industry. The grant for travelling scholarships—with exception of the grant for work masters, foremen, and workmen of 2000 kronor, which up till now has been utilised only in a very small degree—is meant for engineers who have gained sufficient practical training within the Swedish iron industry to enable them to gain increased experience by studying the iron industries of foreign countries. The 6000 kronor granted have been subject to great demands. An increase in these travelling scholarships has been rendered possible by the deceased Baron Louis de Geer, a descendant of the renowned Walloon works owner Louis de Geer, who immigrated into Sweden during the reign of Gustavus Adolphus. By a deed of gift dated July 7, 1918, Jernkontoret received a sum of 100,000 kronor, "the De Geer Fund," the yearly revenue from which, after

reservation of a certain part for increase of the fund, may be disposed of by Jernkontoret for one or more scholarships, to be granted to especially able young engineers, or may be used in other ways particularly profitable or useful for the iron industry. Jernkontoret each year shall decide freely on this matter.

Closely connected with the grant for the technical staff there is another group of grants for technical experiments. During the whole period—1818 to 1870—when Jernkontoret had at its disposal the credit granted by Parliament, it was stipulated that the difference between the interest obtained and paid should be used for experiments. This credit having been withdrawn, Jernkontoret granted a yearly sum for the purpose. Since 1899 this sum has been fixed at 30,000 kroner, "to be used for trials and experiments, also for such other purposes which are regarded by the Board as useful for the development and the advancement of the iron industry, and for which special sums have not been granted." Practically innumerable are the technical reports and researches, the costs of which have been defrayed from this grant. Many of these reports and researches, probably the greater number, have yielded good and important results; but when the reverse has been the case, Jernkontoret has to a very great extent held the opinion that it is better for the iron industry that Jernkontoret should bear the costs for proving the impossibility of an advanced idea, than that one or more part-owners should be involved in expenditure for such a purpose. Where the experiments have been so extensive that the yearly grant available has been considered insufficient, Jernkontoret's Board has not hesitated to propose special grants from the Society. Such proposals were, for instance, made in 1909 for the experimental works at Trollhättan for electric pig-iron smelting, requiring an expenditure of about 300,000 kronor. Through these experiments this important problem was satisfactorily solved. Such special grants have also been proposed and made for the present experiments with the new direct electric iron-making methods of Wiberg and Flodin.

The support of metallurgical research is also the object of Jernkontoret's grant—at present a maximum of 6000 kronor a year—to the Metallographic Institute erected in 1920, the first director of which is Professor Carl Benedicks, one of the hon. vice-presidents

of the Iron and Steel Institute. In the same category is also the sum of 4000 kronor a year, granted by Jernkontoret during 1925 and 1926 to the Government Testing Institute. In this connection it is noteworthy to observe the activity early displayed by Jernkontoret for the advancement of the testing of materials and products of the iron industry. Jernkontoret was a pioneer in this field, and erected in 1874 its own testing department, which was maintained until 1894, when it became attached to the Royal Technical College and amalgamated with its testing department. Jernkontoret engaged itself to support this institution financially, especially for the establishment of a laboratory for metallurgical chemistry. When the Government Testing Institute came into operation in 1920, Jernkontoret allowed its previous grant of 4400 kronor a year to remain during the first five-year period, 1920 to 1924, and for each year (1925 and 1926) it has placed a sum of 4000 kronor at the disposal of the Institute to be used for such research work as should be found of special interest to the Swedish iron industry. A report of the first research work paid for from this grant, relative to the testing of hardened steel, is submitted at this autumn meeting of the Iron and Steel Institute in Stockholm.

When in connection with the erection of new buildings for the Royal Technical College the State wished to obtain full ownership of the ground on which the old buildings of the college were situated—which site Jernkontoret in 1866 had on certain conditions placed at its disposal—an agreement was made between the State and Jernkontoret to the effect that Jernkontoret should renounce its claim in consideration of a grant from the State of 200,000 kronor, to form a fund administered by the Public Treasury. The revenue from this fund (called Jernkontoret's Fund for Scientific Research on Metallurgy and Mining) was to be administered jointly by the board of the Technical College and Jernkontoret for research work, a certain part being reserved to increase the fund. A sum of about 9000 kronor yearly has been made available through this arrangement from July 1, 1924, for the increase of Jernkontoret's own means for the same purpose.

Regarding the technical activity of Jernkontoret, an additional arrangement has been adopted during the current year, from

which good results are expected. In consequence of the strong technical development of the iron industry since 1903, when the last reorganisation of Jernkontoret's technical staff was undertaken, experience has proved that it is hardly possible either for the chief engineer alone to execute the superintending activity which is desirable, or for the technical experts to investigate and roughly sift new questions, which are constantly arising.

Recognising these facts, the Board accepted a proposal made by the editor of *Jernkontorets Annaler* (Mr. A. Grabe) to arrange in connection with Jernkontoret *permanent technical committees* for the different branches of the iron industry, in accordance with the arrangements in several foreign countries. The proposal having been considered by a special committee, the Society in 1926 decided to approve the report of the committee and authorise the Board to carry out the decision. The chief provision of the proposal was that four technical committees should be appointed—one for mining and ore-dressing; one for pig-iron making, including briquetting and sintering of ores and wrought-iron making; one for steel making, together with steel casting; and, finally, one for the mechanical and thermal treatment of iron and steel. Besides the chief engineer, who should act as leading member in all committees, the members should be four in each of the two first named and six in each of the last mentioned. The editor of *Jernkontorets Annaler* should act as deputy for the chief engineer and as general secretary to the committees. Sittings should be held at least twice yearly—one in the spring and one in the autumn. The committees were appointed by the board immediately after the decision of the Society, and the committees are to begin their work in the autumn.

In addition to these new spheres of Jernkontoret's technical activity mention should be made of its co-operation in providing a satisfactory training of technical men for the iron industry. Regarding the higher technical education, imparted since an early period at a school at Falun, Jernkontoret engaged itself about 1865 to bear the costs of the practical summer courses of the students, when this school was transferred to Stockholm and attached to the Technical College. For this purpose a yearly sum of 15,000 kronor was granted, which sum some years ago was

increased and is at present fixed at 20,000 kronor. Jernkontoret also bought, and on certain conditions presented to the State, a site, adjacent to that of the Technical College, to be used for a building for the school of mining and metallurgy. The elementary school established at Filipstad in 1832 and the corresponding school established in 1867 at Falun have from the beginning been administered by Jernkontoret with financial support from the State. According to the latest rules laid down in 1922 for these schools there is at Filipstad one metallurgical course and at Falun one metallurgical and one mining course, each lasting two years. The schools are still connected with Jernkontoret, and are now also subject to inspection by the Royal Board of Education. The cost, according to estimates approved in 1922, amounts to 32,650 kronor for the school at Filipstad, and to 42,700 kronor for the school at Falun, with an additional 2300 kronor for increase in instructors' salaries after long service, making a total of 77,650 kronor. Three-fifths of this amount is paid by the State and two-fifths by Jernkontoret, making for Jernkontoret 31,060 kronor, whereto should be added certain minor grants.

The reorganisation in 1922 of the two schools mentioned involved the definite abandonment of the lower sections or trade classes, which had been formed as part of these schools for the training of capable foremen for the iron trade. In their place there were organised, in collaboration with Stora Kopparbergs Bergslags Aktiebolag, the so-called Jernkontoret's courses for foremen for the mining and iron industry, to which courses Jernkontoret now contributes a sum of about 9000 kronor a year.

With regard to the Swedish iron industry's requirement of charcoal and the considerable areas of forests owned by the part-owners, Jernkontoret has for a long time been actively interested in forestry and charcoal burning. For six years, beginning with 1835, it granted a certain sum for improving the management of the forests, and in 1841 a new institution of forestry was established, which, however, ceased in 1860. Since 1890 Jernkontoret has made large grants in aid of a school for forest wardens in the counties of Värmland and Örebro, which has now absorbed the practical school of charcoal burning in Värmland, supported since 1872 by Jernkontoret. As far back as 1868 a certain sum was granted for

experimenting with a better method of charcoal burning, and in 1878 a grant of 6000 kronor was provided to establish more schools for the purpose. Such a grant—at present raised to a maximum of 20,000 kronor—has since regularly appeared in Jernkontoret's budget.

In addition to this short account of Jernkontoret's work in the training of skilled men for the different branches of the iron industry, something should be said about its efforts to increase knowledge within the scope of its interests and to facilitate the spreading of such knowledge. At quite an early stage Jernkontoret began the practice of giving prizes and honorariums for the production of writings of benefit to the iron industry, and to grant means for their publication. With Jernkontoret's financial support Sven Rinman wrote and published his famous works: "Anledningar till kunskapen om den grövre järn- och stålförädlingen" (On the Manufacture of Heavier Iron and Steel Goods) in 1772; "Försök till järnets historia" (History of the Iron) in 1782; and "Bergverkslexikon" (A Dictionary of Mining and Metallurgy) in 1788–1789; Rinman's and Erik Nordevall's well-known work, "Avhandling rörande mekaniken med tillämpning i synnerhet till bruk" (Treatise on Mechanics, especially adapted for Mines and Ironworks) in 1794 and 1800; Johan Garney's "Handledning uti svenska masmästeriet" (Text-Book on Swedish Blast-Furnace Practice) in 1791; and many others. Several other larger and smaller text-books and papers on different branches of the iron industry have been published by Jernkontoret.

This work of spreading useful knowledge was more permanently organised in 1814, when the Society decided to publish a periodical or *Bergs Journal*, at Jernkontoret's cost. This periodical was started in 1817, and originally appeared twice yearly. Since then it has continued to be published with varying numbers a year—at present one a month, together with an extra number containing the minutes of the meeting for technical discussion. There is no doubt that *Jernkontoret's Annaler*, which in 1917 was able to celebrate its centenary, and probably is the oldest periodical on the iron industry in the world, has been of very great importance, not only to the Swedish iron industry, but to the industry generally.

In this connection it should be mentioned that the Society's support of research and publication has been considerably facilitated in recent years by two deeds of gift by Mr. C. R. Prytz, in Gothenburg, who gave in each of the years 1917 and 1925 100,000 kronor to form a fund, named the Prytz' Fund, for promoting historical research within the iron industry. This fund, together with a collection of pictures of Swedish mines and ironworks, presented by Mr. Carl Sahlin, has given rise to intensive research work, which has already shown good results.

The main branches of Jernkontoret's present activity have now been described. As previously mentioned, the Association in its work has not been fettered by too strict rules. It has been possible, whenever more important enterprises were at stake, to come forward with assistance for both technical and economic interests, of which benefits the industry has largely availed itself. An endeavour to enumerate all the enterprises to which Jernkontoret in one way or another has lent its support would be too great a task, as it would certainly involve the recording of most of the new projects and achievements of the iron industry.

There still remains one thing to be mentioned. As already pointed out, Jernkontoret developed early into a centre of the Swedish iron and steel industry—a position which has grown stronger with the passage of time, both internally in relation to the part-owners as well as externally in relation to the official authorities. The part-owners have grown accustomed to seek the help of Jernkontoret on all matters of common interest, such as legislation, traffic, and customs; and this position as the representative of the Swedish iron and steel industry, having become traditional, is accepted by the official authorities, who readily receive Jernkontoret's proposals and increasingly regard the Association as the authority for reports on important questions affecting the iron industry.

That Jernkontoret has been able for so long to exist and work for the benefit of the Swedish iron industry is mainly to be attributed to the circumstance that it has been fortunate in obtaining good executive deputies and collaborators. The relations between the Society and Jernkontoret have been characterised by a confidential collaboration, and the position of delegate to Jernkontoret, or as deputy to assist in the audit, has

always been appreciated as a proof of the estimation of the Society. Consequently, in the long list of delegates we find the majority of the pioneers of the Swedish iron industry, which makes it very difficult to mention special names. The presidents of the Board have generally been persons who, being in one way or another associated with the iron industry, have at the same time occupied prominent public positions in other respects. Amongst these should be mentioned the Governor-General of Stockholm, Baron C. G. Tamm, and Major-General S. G. A. Geijer.

Of Jernkontoret's technical experts some have already been mentioned, and other prominent ones may be recalled to mind: the chemists and naturalists, T. O. Bergman, C. W. Scheele, J. J. Berzelius; Gustaf Ekman, who in the thirties introduced the Lancashire forge into Sweden; E. Westman, the constructor of the roasting kiln bearing his name, which is commonly used in Sweden; G. F. Göransson, who introduced and perfected the Bessemer process; N. G. Sefström, Joachim Åkerman, Knut Styffe, Richard Åkerman, and F. A. von Scheele.

Jernkontoret's Board is at present composed as follows: Regular deputies: Bank Director Mr. J. Carlsson Kjellberg, President; Magistrate Mr. Emil Kinander, Managing Director; Count Gösta von Rosen, works owner; Major Baron Herman Fleming; and Managing Director Mr. A. Sjögren. Vice-deputies: Count Henning Wachtmeister, Lord-in-Waiting; and Managing Director Mr. Kr. Huldt. Extraordinary delegates: Mr. August Herlenius, First Gentleman to His Majesty the King; Baron C. J. Beck-Friis, works owner; Messrs. Carl Sahlin, Tord Magnuson, and Emil Lundquist, works managers. Vice-delegates: Messrs. Ernst Odelberg, works manager; A. Gerh. Arfwedson, works owner; Wiking Johnsson and Elis Wettergren, works managers; and Lars Uno Lindberg, works owner.

For the honouring of men who have achieved special merit in the Swedish iron industry, Jernkontoret possesses from olden times two marks of distinction.

The first of these is the great Gold Medal of Jernkontoret, struck for the first time in 1751, in homage of King Frederick I., in whose reign the Association was founded, in 1747. The obverse of this medal shows the King's image, and the reverse is ornamented with symbols of the iron industry and bears the legend

from Virgil, "Hortor amare focos," together with the year and date of the royal sanction of Jernkontoret's establishment. The Board has the right to award the medal to such persons as have displayed special merit in the advancement and development of the Swedish iron industry, or who have worked in a specially meritorious way for the benefit of the Society. The medal is regarded as a very high distinction; of those to whom it has been awarded only five are now living.

By Royal ordinance of June 11, 1822, Jernkontoret's Board has further the right to award a medal in silver or gold as a token of distinction, with the inscription "For zeal and ability in the iron trade," to be worn on a chain round the neck. This medal, which on the obverse shows several symbols of the industry, and on the reverse bears the above inscription, is awarded in silver to especially capable foremen and workmen. According to the Royal ordinance it can be awarded in gold only when extraordinary merit has been shown. On account of these strict conditions, this gold medal has so far been awarded only five times: to *Bergmästare* F. A. von Scheele, in 1832; the director of bar-iron forging, J. P. Morell, in 1844; the works owner, Gustaf Ekman, in 1868; the chief engineer, J. A. Brinell, in 1914; and the chief engineer, Gustaf Jansson, in 1926; of whom the last mentioned is the only one still alive.

Finally the Society, in 1917, in accordance with a proposal originally made by Brinell, in order to celebrate the centenary of *Jernkontorets Annaler*, resolved to institute a medal in gold to be awarded as a prize for scientific research within the field of the Swedish iron industry. The medal bears on the obverse the image of Sven Rinman, in whose memory this medal has been named the Rinman Medal, and on the reverse a symbolic illustration of man's endeavours to penetrate into the well of knowledge, together with the inscription, "For scientific research, by Brukssocieteten." Competition for this medal has hitherto occurred every third year, and until the present time the medal has been awarded only once, in 1921, to J. A. Brinell.

Some notes on Jernkontoret's premises and financial circumstances may also be of interest. Even before the establishment of Jernkontoret had received the royal sanction in 1747, in 1745 a locality had been rented in a house at Svartmangatan, at present

Nr. 6. In the following years the offices were housed in different rented premises, but in 1756 a property at Lilla Nygatan, at present Nr. 17, was bought. In 1829, the house of the Academy of Sciences at Stora Nygatan, now Nr. 30, was bought, and there the Association was accommodated until the middle of the seventies. At that time ground belonging to the so-called Schulzenheim estate was bought, and a new building was erected on part of it, at the corner of Arsenals- and Kungsträdgårdsgatan. Here Jernkontoret is still housed. The building, constructed by the architect W. Kumlin, is ornamented externally with a frieze running below the roof, sculptured by Professor F. R. Kjellberg, representing scenes from the history of the Swedish iron industry. On the façade and inside are a number of medallion portraits of men renowned in the industry.

Finally, some words about Jernkontoret's finances. Except the voluntary payments, made by some works owners during the years 1745 to 1747, Jernkontoret's first, and for a long time most important, income consisted of the "Jernkontorsdaler," which is still paid at the rate of $2\frac{1}{2}$ öre per centner ($42\frac{1}{2}$ kg.).

In addition to this there was soon derived an income from interest on loans, which income from the beginning of the nineteenth century began to exceed that from the daler, and it has since so continued in a rising degree. In 1925 the income in round figures from the daler was 41,200 kronor, and from interest 446,000 kronor net. Other sources of income have generally been of minor importance. Amongst these we find payments for introduction of new parts, grants from the State (at present for the technical schools in Filipstad and Falun), income from literature sold, &c.

On the expenditure side the items have naturally been more numerous and varying. For the Memorial Exhibition in Gothenburg in 1923 there was prepared a summary of Jernkontoret's expenditure for the advancement of the iron industry during the years 1748 to 1922. This table has been completed up to 1925, and the figures of this last-mentioned year have been recorded separately. It shows that Jernkontoret from the beginning, in 1747, up to the end of 1925, has expended the following sums for the purposes mentioned, the last year being shown separately :

	1748 *to* 1925.	1925.
	Kronor.	Kronor.
Salaries for technical experts, scholarships, travelling scholarships, prizes	5,471,631·79	120,607·01
Experiments and trials, including experiments on electrical pig-iron making, grants for laboratories, testing institution, and metallographic institute	1,247,578·06	96,722·58
Royal School of Mines and Metallurgy in Stockholm, for students' practical courses	631,490·33	21,694·46
Schools at Filipstad and Falun and foremen's courses, *less* grants from the State	1,456,594·24	50,081·60
Schools for charcoal burning, including Jernkontoret's Institute of Forestry, 1839–1860	554,067·88	20,303·60
Jernkontorets Annaler, technical meetings, technical literature, &c.	2,436,224·37	56,829·33
For trading interest of the iron industry, &c.	855,587·99	8,399·95
Exhibitions, congresses, &c.	203,320·92	742·50
Medals, memorials, portraits	130,704·63	4,519·58
Sundries	254,313·91	6,588·40
Total	13,241,514·12	386,489·01

More detailed information regarding Jernkontoret's economic circumstances as they have developed since the World War will be found in the attached statements of Jernkontoret's income and expenditure together with a balance-sheet for the year ended December 31, 1925.

The loss of about 58,400 kronor shown is fortuitous, and is due to the extraordinarily high expenditure for experiments, and more especially for the new methods of iron-making by Wiberg and Flodin.

Already in 1750 Jernkontoret was able to record the possession of a capital amounting in the coinage of to-day to 57,235 kronor, 80 öre. The capital has since that time almost continuously increased, and the rate of increase is shown by the following figures at the end of each twenty-five year period:

	Kronor.
1750 (Capital)	57,235·50
1775 ,,	554,883·37
1800 ,,	1,073,497·50
1850 ,,	3,324,853·50
1875 ,,	5,212,524·00
1900 ,,	5,731,813·47
1925 ,,	9,333,772·78

It should be noted that, of the increase in the period 1900 to 1925 of about 3,600,000 kronor, not less than 1,500,000 kronor was derived from the above-mentioned increase of introduced iron—that is, increase of the partnership in Jernkontoret.

This short account of Jernkontoret's establishment, development, and present activities is, as regards the historical part, mainly a summary of the paper compiled by the deceased State Antiquary, Dr. Sam Clason, on the occasion of the centenary of *Jernkontorets Annaler*, with the title: "Some Features of Jernkontoret's History." Due, unfortunately, to his premature decease, this justly celebrated man, the warm friend of Jernkontoret, did not have the opportunity of fulfilling his expressed desire to write its complete history in detail. Regarding Jernkontoret's present activity this account is treated and, for the period 1916 to 1925, completed more personally.

In submitting these modest notes to the renowned Iron and Steel Institute, I venture to express the hope that its members may be interested to have some information about the old Swedish institution which, broadly speaking, is working towards the same end as that Institute.

JERNKONTORET.

Income and Expenditure per 31st December 1925.

DEBIT.

Assets January 1, 1925	Kr. 11,539,922·58	
Liabilities on the same day	2,147,758·18	
		Kr. 9,392,164·40
Revenue.		
Interest	Kr. 521,738·19	
Jernkontoret's dues (The "Jernkontorsdaler")	41,251·88	
State grant, for the Mining Schools at Filipstad and Falun	57,985·80	
Jernkontorets Annaler: for copies sold and advertisements	10,902·63	
Commissions and various revenues	4,074·50	
Fees for credits and running accounts	18,532·08	
Jernkontoret's house: rent, &c.	13,235·00	
		667,720·08
Total		Kr. 10,059,884·48

CREDIT.

Expenditure.	
Interest	Kr. 94,350·30
Jernkontoret's salaries	80,944·62
Extraordinary delegates' travelling expenditure and allowances	1,782·10
District deputies' travelling expenditure and allowances	830·95
Carried forward	Kr. 177,906.97

CREDIT (*continued*)—*Expenditure.*

Brought forward .		Kr. 177,906.97	
For technical assistants, travelling allowances and remuneration		113,839·01	
Mining and Metallurgical School at Stockholm		23,257·19	
,, ,, ,, ,, Filipstad		42,809·49	
,, ,, ,, ,, Falun .		55,824·27	
Foremen's courses for mining and iron-making		9,268·64	
Jernkontorets Annaler, expenses . . .		55,585·96	
Grant for experiments and trials . . .		32,326·14	
Wiberg process		30,730·75	
Flodin process		25,453·85	
Grant for Charcoal-burning Schools . .		13,303·60	
Forest Wardens and Charcoal Burners School for the counties of Värmland and Örebro .		7,000·00	
State Testing Institute		4,000·00	
Technical Discussion Meeting . . .		6,630·35	
Metallographic Institute		2,211·84	
Pensions for officials and servants . .		11,054·35	
Pensions Account for widows and children .		6,202·55	
For charitable purposes		2,000·00	
Inventory : new purchases . . .		1,043·00	
Jernkontoret's picture collection . . .		4,824·83	
Writing-off of shares		11,499·00	
Expenditure Account.			
Payments for newspapers and to Associations, &c. . . .	Kr. 5,515·25		
From grants made for various purposes	28,672·79		
Costs of committee works . .	1,588·40		
Cost of total maintenance of Jernkontoret's house, and inventory	27,144·20		
Fuel and lighting . . .	6,255·06		
Various expenditure . . .	20,163·21		
		89,338·91	
			Kr. 726,111·70
Assets the 31st December 1925 . . .		11,520,169·98	
Liabilities on the same day . . .		2,186,397·20	
			9,333,772·78
Total			Kr. 10,059,884·48

Jernkontoret's Position on the 31*st December* 1925.

ASSETS.

Jernkontoret's house	Kr. 450,000·00
Inventory	1,000·00
Bonds, Swedish State	186,850·80
,, General Mortgage Bank	488,095·00
Shares	1·00
Cash	33,693·00
Mining School at Falun (advance)	1,751·19
State grant to mining schools, due	14,470·50
Text-books on charcoal burning	1·00
In account with bankers	1,583,158·62
Carried forward .	Kr. 2,759,021.11

ASSETS (*continued*).

Brought forward .		Kr. 2,759,021.11
Outstanding loans :		
Advanced loan at 4·5 per cent.	Kr. 5,520,400·00	
Building loan at 6 per cent.	160,000·00	
Other loans to part-owners	339,500·00	
Loans to other than part-owners	773,103·39	
		Kr. 6,793,003·39
Credit at bank		458,895·11
Current accounts		1,253,042·20
Post Office current account		4,727·95
Accrued interest		251,480·22
Total		Kr. 11,520,169·98

LIABILITIES.

Deposit Account		Kr. 1,577,930·93	
Current Account		320,065·78	
Post remittance cheques		17,186·90	
Metallographic Institute		28,363·83	
Miscellaneous invoices		15,529·15	
Prytz' Fund		101,071·64	
De Geer's Fund		113,254·49	
Accrued interest		12,944·48	
			Kr. 2,186,397·20
Main Fund		5,553,940·72	
Reserve Fund		2,001,346·88	
General Fund :			
Liability Fund	Kr. 37,444·01		
Other funds	1,741,041·17		
		1,778,485·18	
			9,333,772·78
Total			Kr. 11,520,169·98

DISCUSSION.

The President thought the members were very much indebted to the author for his extraordinarily interesting paper; it would for all time be a very interesting record of a wonderful Institution of which Great Britain was quite unable to furnish any counterpart in the same sense.

It was a remarkable fact that to the Swedish Ironmasters' Association belonged the credit of having been the first to recognise the wisdom of giving financial aid in promoting technical and scientific research for the improvement of their practice in the art of iron-making, and that aim they had consistently pursued since the middle of the eighteenth century down to the present time. The Association, in fact, had the unique distinction of being probably the only one in existence which promoted two principal objects—namely, the promotion of the commercial interests of the iron trade and the fostering of technical improvements in the industry.

It afforded him much pleasure to ask the members to pass a very hearty vote of thanks to the author for his very interesting and valuable paper.

The resolution of thanks was carried with acclamation.

THE DEVELOPMENT OF THE SWEDISH IRON INDUSTRY DURING THE LAST THIRTY YEARS.*

By ARVID JOHANSSON AND AXEL WAHLBERG (STOCKHOLM).

WHEN the Iron and Steel Institute, in the year 1898, held its meeting in Stockholm, Richard Åkerman, Bessemer Medallist and one of the first Honorary Members of the Institute, presented an extremely interesting paper on the development of our Swedish iron industry from the very remote times when malleable iron, so-called "Osmund," was produced direct from bog ore in small open furnaces or, rather, hearths, down to the end of the nineteenth century.

Åkerman guided us through one century after another. We learned how pig-iron was probably produced for the first time in the middle of the fifteenth century, but that it was not until about one hundred years later that the manufacture of pig-iron was regularly established. And then came the time when the refining methods were developed.

Now, the purity of the Swedish ores, our great forests, and an abundance of water-power, gave Sweden quite a predominating position as regards the world's supply of iron and steel. As a matter of fact, Sweden was for a long time the greatest iron-producing country in the world, and in the two decades 1720 to 1740 Sweden's iron production was twice as large as that of Great Britain.

But this happy condition changed at the end of the eighteenth century, when Cort introduced his puddling process, whereby it became possible to eliminate the greater part of the phosphorus during the refining, and consequently an iron of fairly good quality could be made from ores containing a considerable amount of phosphorus.

About half a century earlier Darby had succeeded in using

* Received July 3, 1926.

coke in the blast-furnace. This invention naturally was of the greatest importance for every iron-producing country, which—unlike Sweden—possessed coal deposits; but it was the puddling process, together with the simultaneous invention of the steam-engine, that actually brought about a complete revolution not only in the making of iron, but also in practically every other industry. From that time, it may be said, industrialism gradually obtained its iron grip on the civilised world.

The Swedish iron industry, however, received a still greater blow when, in 1820, Rogers, also an Englishman, made his invention of the basic lining in the puddling furnace, thus making possible the production of iron still lower in phosphorus, and containing less enclosed slag and other impurities.

From that time the Swedish iron industry ceased to hold its position as a chief supplier in the world's great iron markets. But in spite of this lamentable fact our industry never stood still. We have—thanks to our pure ores and abundance of charcoal—always been able to make iron of the highest quality, and to find a market for our products.

When later the manufacture of steel by the Bessemer and the open-hearth processes was introduced, these methods proved especially helpful to us in producing high-grade steel. When finally it was found that these processes could be usefully worked with basic linings, this led naturally to developments of the greatest importance in other countries for making soft steel of ordinary quality; but we here in Sweden were also able to profit by making soft steel of the very highest quality.

In a manner all these metallurgical developments have injured our trade, because with every one we lost certain markets for our Swedish iron and steel; but, happily, owing to the rapid development of the mechanical industries, the demand for iron and steel of the highest standard has continually increased, and new fields have opened up. We also dare hope that this fortunate circumstance may prevail for ever, to the benefit, not only of Sweden, but of every country that produces steel of the highest standard.

It is unnecessary, however, to dwell further on the events of the past, and we will proceed to try and present some idea of what has been done in Sweden during the last thirty years in developing our own iron industry.

Raw Materials.

The Iron Ore.—The Swedish iron industry is mainly still based on the ores of Central Sweden, which are very low in phosphorus and sulphur. Thus the blast-furnace burdens of the steel-producing works still contain the old well-known ores: Bispberg, Dannemora, Dalkarlsberg, Norberg, Nyäng, Persberg, Taberg, Stripa, Striberg, Ställberg, &c. Of ores from the north of Sweden it is only the particularly pure Tuolluvaara ore that during the last twenty-five years has to a limited extent been used by ironworks in Central Sweden. The principal ores for Swedish Lancashire iron are still the ores from Dannemora, Norberg, Striberg, Stripa, Vintjärn, &c.

In the course of time there had accumulated at our mines large quantities of waste low-grade ore—40 per cent. iron or less—which it had been impossible to utilise owing to their low percentage of iron. Rational mining necessitated taking out the low-grade with the richer ore, but the use of the low-grade ore in the blast-furnace steadily diminished, as the costs gradually increased on account of the higher cost of charcoal, railroad freight, and labour. Under such circumstances it was only natural that efforts should be made to concentrate these low-grade ores. Trials with this object were set on foot at the end of last century, and not without success; but the resulting product, fine concentrates—so-called "slig"—did not prove suitable for use in larger quantities in the blast-furnace, at least not in the condition in which it left the mine. Besides, it was often rather too high in sulphur. Suitable furnaces for roasting fine concentrates were built, but their output was small, and there always remained the difficulty that the use of fine concentrates may lead to scaffolding in the blast-furnace. It was therefore necessary to combine the concentration of the low-grade ores with agglomeration of the fine concentrates, and it was in this manner that the problem was solved, through the efforts of Dr. Gröndal, in the beginning of the century. The ores are now utilised as follows: They are crushed in a stone-breaker, ground in a ball-mill, treated by wet magnetic separation, and the fine concentrate is agglomerated by briquetting or sintering. The latter processes are, however, as a rule carried out at the blast-furnaces.

Work on these old ore dumps was started at practically all the larger ore fields, and at first a concentrate as high in iron as possible was sought for; 65 per cent. of iron or more was rather usual. It soon became evident, however, that in trying to reach this high percentage of iron the cost was much increased—partly on account of the necessity of finer grinding, and partly on account of the growing waste. It was also found that this high percentage of iron was a disadvantage when making pig-iron of the very highest quality. For the last fifteen years it has therefore been usual to keep the iron between 58 and 64 per cent. in the concentrates consumed in our charcoal furnaces when making pig-iron for conversion into the higher qualities of steel. This enabled the cost of concentrates to be reduced, and, what is more important, the remaining gangue—about 15 per cent.—provides the necessary protection against the burning of the iron in the blast-furnace.

These old ore dumps are, however, now practically all used up, and concentration is limited to the lean ore obtained when mining for lump ore. The iron content of the latter is generally 50 to 60 per cent. As a matter of fact, lump ores still form the bulk of the ores used.

Although some of our mines in Central Sweden are worked down to a considerable depth, the ore-bodies have so far not shown any diminution. On the contrary, new ore-bodies have, as a rule, been discovered. Neither has the quality deteriorated. The foundation of our high-grade iron industry is consequently secured for all reasonable time, as far as the ores are concerned.

The Charcoal.—Since the earliest period of our iron industry the demand for charcoal has been met by burning in heaps. About 1900 the practice of carbonising in ovens began to gain ground, and during the last two decades about 10 per cent. of the charcoal supply has been produced in ovens with the recovery of by-products. As far as can be foreseen at present, an increased percentage of the total charcoal produced will be carbonised in ovens in the future.

The fact that carbonisation in ovens has not been more widely adopted is largely due to the quality of the raw material. The soft wood used in Sweden for carbonisation gives a poor yield of by-products as compared with the hard wood used abroad. Further drawbacks are the cost of transportation of the wood to

the charcoal plants and the relatively high cost of the erection of such plants.

The normal charcoal consumption of the Swedish ironworks before the war was 4·2 million cubic metres per year, the value of which at the present day is about 25 million crowns.

Heap Carbonising.—The original methods of carbonising in heaps are still used, with some modifications. However, horizontal heaps are being replaced by vertical heaps.

Mainly on the initiative and at the expense of Jernkontoret, schools have been established to provide skilled workmen for heap charcoal burning. Since 1872, when the first school was started, Jernkontoret has contributed about 360,000 crowns to the maintenance of these schools, which have been attended by about 4000 pupils.

In recent years careful investigations have been carried out at the expense of Jernkontoret, with the result that even the carbonisation process in heaps has become more clearly understood.

Carbonising in Ovens.—About 1820 the Schwartz ovens were built in Sweden for carbonising wood, but without provision for by-product recovery, and they failed to achieve any important improvement for our iron industry. Not until Ljungberg's ovens (a modification of the Schwartz oven) were erected at Domnarfvet about 1890 can it be said that the problem of recovering the by-products was satisfactorily solved. The extensive investigations which at that time were carried out at Domnarfvet to find methods for the recovery of acetic acid, methyl alcohol, and other products can rightly be considered as pioneer work.

In the years following 1900 there was considerable activity in the construction of charcoal ovens, and the development aimed at both obtaining higher yields of charcoal and by-products, as well as improving the quality of the charcoal. Indeed, in view of the low yield of by-products from the soft wood it was an economic necessity in our country to develop methods both of carbonising and of by-product recovery superior to those in use in other countries.

Investigations have been made and are further planned for the purpose of increasing the economic yield of the by-products. The cost of these investigations is borne by Jernkontoret and Ingeniörsvetenskapsakademien, among others.

The value of the by-products produced in 1924 was about 2,300,000 crowns, whereas the corresponding figure for 1900 was only 270,000 crowns.

The Wood.—Before 1915 there was carbonised on an average 9 million cubic metres of piled wood per annum, or more than 10 per cent. of the total output of wood in Sweden.

The development shows that the charcoal-burning industry has more and more to depend on raw material which is unsuitable for use in other industries. In 1913 there was produced about 1 million cubic metres of charcoal from sawmill waste alone, which was equal to about 24 per cent. of the total charcoal supply. However, since this waste has now found an increased use in the pulp industry, the production of charcoal at the sawmills has considerably decreased.

Also, as regards wood from the forests, the sulphite and, still more, the sulphate industries appear as strong competitors to charcoal burning.

Nevertheless, it is likely that the supply of raw material will always suffice to meet at least the present charcoal demand of the Swedish industry. This has been proved by very thorough researches in Norrland, Dalarne, and other places by a Royal Ore Commission and Jernkontoret.

Extensive investigations regarding the percentage of phosphorus in charcoal produced from different kinds of wood have been made by Åkerman and Särnström, and quite recently by H. von Eckermann. These investigations show that Sweden has great quantities of wood material with a very low percentage of phosphorus, thus suitable for making charcoal for the iron and steel industry.

The Power Supply.—In olden times the only source of power was water, and for centuries water-wheels directly connected to the machines were used. It was not until the middle of the last century that the water-turbine first came into use.

In those old days there were no means of transmitting power to a distance, for which reason all our ironworks were built close to the waterfalls, no matter whether the site were otherwise suitable or not. This explains the difficulty we find in modernising our old Swedish works.

The introduction of steam towards the end of the eighteenth

century, which revolutionised the industry and communications of the whole world, had also a great influence on the Swedish iron trade, although not to such an extent as in most other countries with a large supply of fossil fuel. In Sweden the water-power has always been predominant, and the steam power has taken second place. But with the introduction of electricity undreamt-of opportunities presented themselves for planning our works rationally, and also for modernising practically the entire equipment. In fact, electricity has enabled us well-nigh to remodel the whole iron industry of the country.

For lighting purposes, direct electric current had been in use since the early eighties, but it was not until 1890 that the alternating current made its appearance. The Swedish ironworks were immediately ready to utilise this invention, and electric motors were installed as motive power in old as well as in recently erected rolling-mills, the power being transmitted from a near or distant waterfall. A brief description of this evolution will be given later.

The hydro-electric power was early used also for metallurgical purposes. Thus F. A. Kjellin constructed the first electric induction furnace for melting steel at Gysinge in 1899, and eight years later the trials were begun in smelting pig-iron in an electric furnace at Domnarfvet. These experiments have, as will be mentioned later, given rise to an extensive use of hydro-electric energy in the production of pig-iron and steel.

In 1925 T. Holmgren carried out an extensive investigation of the power question of the Swedish iron industry, from which we give the following data concerning electric pig-iron.

In 1923, according to published statistics, there were produced in Sweden 52,148 tons of ordinary electric pig-iron with a consumption of energy of 132·2 million kilowatt-hours and 1,331,464 hectolitres of charcoal, or 2540 kilowatt-hours and 25·5 hectolitres for 1 ton of pig-iron. On a yearly production of, say, 500,000 tons of pig-iron, exclusively electric, we should save 18 million hectolitres of charcoal—that is, 18 million crowns, reckoning the price at 1 crown per hectolitre. If the electric power could be obtained at a price of 0·8 öre per kilowatt-hour, the cost of the power would amount to 10 million crowns, and the real saving to 8 million crowns, apart from interest and depreciation. After

allowing for these items the net saving would probably amount to 4·5 to 5 million crowns.

This calculation shows us that it would be an economy to substitute electric furnaces for blast-furnaces, provided that the electric energy can be obtained at a reasonable price. The economy would naturally depend also upon the future price of charcoal, the higher the price the greater being the saving by the use of the electric pig-iron furnace.

The following figures will show the amount of water-power obtainable in Sweden. The figures refer to an average year with normal water supply and greatest possible care to prevent any waste of water.

	Millions of Kilowatt-Hours.
South and Central Sweden	7,600
Lower Norrland	9,900
Upper Norrland	15,000
Total	32,500

The electric power produced in 1923 amounted only to 2980 million kilowatt-hours, or 9·1 per cent. of what can be obtained. From this it will be seen that there are possibilities for a very extended use of electric power.

The Swedish Government has equipped its own waterfalls at Trollhättan, Älvkarleby, Porjus, Motala, and Lilla Edet for the generation of electric power, and from there the power is distributed to a number of works, including ironworks. Other waterfalls, belonging to the ironworks, have been equipped by the firms chiefly for their own use.

In this connection may be mentioned the advantages obtained by co-operation. In 1917 there was formed a power company for the supply of power to, and co-operation with, a number of power consumers and producers. This has met with success, and the transmission and distribution lines of twelve ironworks, eight mines, and five independent power-stations are now connected with the main line of the power company, the total generating capacity of the system being about 125,000 kilowatts.

The interconnection of the many power producers results in a more constant load—that is, a better load factor—and the surplus power can be disposed of. Variation of load, peak loads, and

over-loads are taken care of by the main system, and there is less need for reserve or spare plants than when working independently.

Pig-Iron Production.

The development of Swedish pig-iron production during the last twenty-five years is characterised by the introduction of the electric furnace, where a certain portion of the charcoal has been replaced by electric energy transformed into heat.

Blast-Furnaces.—The inside dimensions of the ordinary blast-furnaces are in the main unchanged, except that the diameter of the hearth has been increased a little and the shaft has been lowered somewhat, resulting in a lower bosh. These changes were first made by H. Tholander at the beginning of the century, and have now been carried through at most blast-furnaces, with very good results both as to smooth running and increased output. A high grade of charcoal iron, uniform in analysis and of best quality, is evidence of uniformity in the smelting process, and the widening of the lower part of the stack has proved to be of benefit in this respect. When new furnaces have been built or old ones rebuilt, the height of the stack has also been increased in order to diminish the consumption of charcoal and at the same time increase the output. Formerly the hearths almost always had a rammed lining of crushed quartz and fireclay, but are now mostly lined with silica bricks or fireclay bricks.

Dimensions, &c., of Swedish Charcoal Blast-Furnaces.

	Blast-Furnace from about 1890.	Built 1915.
Inside height . . .	15·6 metres	18·0 metres
Diameter of bottom of hearth	1·4 ,,	1·9 ,,
Diameter of bosh . .	2·8 ,,	3·0 ,,
Height to top of bosh . .	4·6 ,,	3·5 ,,
Cubic capacity . . .	66·4 m.^{3}	89·7 m.^{3}
Weekly production . .	115 to 130 tons	175 to 200 tons

When building new furnaces or modernising old ones efforts are made to cheapen the production by the introduction of labour-saving appliances for the handling of charcoal, ore, and pig-iron.

Nowadays the charcoal is nearly always delivered by rail, and

is stored in charcoal sheds, as far as possible. To permit of stacking higher than the railroad tracks, the charcoal sheds are in many places provided with a steel belt conveyor, which at an inclination of 13° passes from a hopper outside the shed up to and under the ridge of the roof, the whole length of the shed. The steel belt is provided with an adjustable discharger. When building new charcoal sheds it is even customary to dispense altogether with railroad tracks inside the shed, and the steel conveyor alone is used.

The charcoal is transported from the shed to the blast-furnace by means of an aerial rope-way, and inside the shed by suspended rails. Screening and loading, which was formerly done by hand, is now done by motor-driven portable screening and loading machines.

The treatment of the ore depends on the condition in which it arrives. Lump ore is roasted as formerly in a Westman roasting kiln, fired by blast-furnace gas, in order to remove sulphur and make the ore more reducible. Crushing to size suitable for roasting (100 to 125 millimetres) is increasingly carried out at the mine, doing away with the former breaking by hand at the blast-furnace. After roasting, the ore is further broken to a size of 20 to 40 millimetres, to be suitable for the blast-furnace. In modern furnaces the roasted ore goes from the roasting kiln to large ore bins, then to the crusher, and then, by automatic hoist and distributor, to the small ore hoppers on the top of the furnace.

The agglomeration of the fine concentrates, as before stated, is done either by briquetting or sintering. For briquetting, the Gröndal method is used. The suitably moistened concentrate—as a rule magnetite—is pressed into briquettes, 150 × 150 × 65 millimetres, which are placed in two layers on a wagon lined with firebricks. No special binding medium is used. The cars are transferred to a tunnel furnace, fired with producer-gas through the roof, in the middle of the furnace. After the water has evaporated and the briquettes have been preheated, the final burning is done at a temperature of 1200° to 1300° C. When passing through the discharge end of the furnace, the air for combustion is preheated by passing over the briquettes, whereby at the same time an oxidation takes place. Well-burned, firm briquettes have been oxidised to between Fe_3O_4 and Fe_2O_3.

By the process of briquetting, the sulphur content of the con-

centrates is reduced considerably. In concentrates with an excess of silica it is easy enough to reduce sulphur from 0·2 per cent. to less than 0·01 per cent. Concentrates from ores containing lime, which often also contain sulphur, are mixed with concentrates containing some free silica, for the removal of the sulphur. When such briquettes are burned gypsum is first formed, but when the maximum temperature is reached the silica combines with the lime and the sulphur is expelled. Different concentrates are also mixed to get more compact briquettes or better fluxing conditions in the blast-furnace. The first briquette furnace was built at Bredsjö in 1902, shortly followed by the erection of similar ones at most of the larger blast-furnace plants.

The cost of briquetting soon proved, however, to be higher than was at first calculated. It necessitated a great deal of manual labour, and when during the war the cost of labour, and especially of fuel, increased very much, attention was directed to the Greenawalt sintering method. By this method it was not necessary to make briquettes, and it was possible to use as fuel the charcoal screenings, which up till then had been of practically no value. A change in the method was made, within the last few years, in such a way that circular pans holding 1 ton are used instead of the large rectangular pans holding 3 to 4 tons of concentrates, and this has resulted in cheaper building costs without any increase in running expenses.

The sintering of concentrate seems as effective as the briquetting process, both as regards removal of sulphur and the suitability of the product for the blast-furnace. As the sintering process does not necessitate the use of a so uniformly fine crushed material as the briquetting, it has during the last years to some extent also been applied to the desulphurising of crushed, but not concentrated, lump ore. In this way a relatively cheap sintered product is obtained, and all the accompanying gangue is melted with the ore in the furnace. Both the briquettes and the sinter are crushed to a somewhat coarser size than the lump ore before charging in the furnace.

The proportion of briquettes or sinter to lump ore used in the charge depends on the supply and character of the concentrates, the percentage of iron in the burden, &c. When the concentrates are made from ores in which the matrix surrounds the small ore

grains, which is the case with most of our pure, so-called "skarn-ores," there is practically no change in the character of the slag due to their use. The iron content in such concentrates is as a rule lower than in concentrates made from magnetites with coarser ore grains, which latter are more easily separated from the gangue on account of their larger size, and therefore less gangue is contained in the finished product. When briquettes or sinter are made from skarn-ores a larger percentage may be used in the burden than when made from coarse-grained ore. The usual amount of briquettes or sinter for steelworks blast-furnaces is from 0 up to 30 per cent. of the burden. Their use promotes smooth running and decreases the charcoal consumption by about 10 per cent. The percentage of iron in the burden is kept at about 50 to 55 per cent. If a richer burden is used, there is a decrease in the protection afforded by the slag when passing the tuyeres, especially for such burdens where the main ores are not self-fluxing, and where the slag is formed by fluxing different ores with each other or with limestone.

The Swedish iron-maker takes great account of the gangue mixed with the ore and is careful to allow it to melt together with the iron in the blast-furnace so far as it contains minerals which are characteristic of the ore and intimately mixed with it. Therefore the concentration of the ore must be carefully performed, and the percentage of non-concentrated ore in the burden should be kept as high as possible.

The slag aimed at is usually about sesquisilicate or between sesquisilicate and bisilicate. It is cast into bricks in cast-iron moulds as formerly, or is granulated by a jet of water. Slag bricks are nowadays only used for foundation work, and the granulated slag for road material.

The blast pressure in the charcoal furnaces is still kept at 60 to 100 millimetres mercury gauge. The old water- or steam-driven blowing engines have in many cases been replaced by electrically driven rotary blowers or high-pressure fans. The blast is still heated by blast-furnace gas in hot-blast stoves with horizontal cast-iron pipes, the thermal efficiency being hardly 30 per cent., though one of quite new design lately erected at Sandviken has an efficiency of about 55 per cent. But it is not intended to increase the temperature of the blast, because

a blast temperature of not over 400° C. has been found to give the best pig-iron.

Since the beginning of the century there has been a rapid increase in the price of charcoal, for the reason that, as mentioned above, wood suitable for charcoal can now be more economically used for pulp. The increase in cost of the pig-iron caused thereby has been to some extent compensated for by the improvements in blast-furnace practice and design, but there is not much more to be done in this direction. A Swedish blast-furnace running on high-quality pig-iron for the acid open-hearth consumes at present about 55 hectolitres of charcoal per ton of iron, and it is only in specially favourable circumstances that the charcoal consumption can be brought down to 50 hectolitres.

Pig-Iron Production by Electric Power.—With the rapidly increasing use of electric energy at the beginning of the century the idea was conceived of replacing the charcoal used in the blast-furnace by electric energy transformed into heat. The only charcoal needed would then be that necessary for the reduction of the iron. A small experimental furnace for this purpose was designed by A.B. Elektrometall, and built at Domnarfvet in 1907, with the result that, at the expense of Jernkontoret, a full-size furnace was erected at Trollhättan in 1910. The Government power station at the same place furnished the necessary electric power.

The furnace fulfilled all expectations. Thus a high quality charcoal pig-iron could be produced with a charcoal consumption of only about 25 hectolitres and a power consumption of about 2500 kilowatt-hours per ton of iron made. It was built for an energy consumption of 2000 kilowatts, and was provided with four carbon electrodes, 660 millimetres square, inserted in a slanting direction towards the centre of a cylindrical hearth. From the top of the hearth rose a vertical shaft, into which charcoal and ore were charged with the usual apparatus, and became preheated by the ascending gases, formed by the reduction. After passing through the shaft, part of the gases were returned to the hearth by means of a fan, in order to cool the roof around the electrodes and also to increase the reducing action of the carbon monoxide. Later furnaces have been built with six electrodes of a diameter of 600 millimetres, and at one place Söderberg electrodes are used with good results.

The pig-iron produced proved to be of excellent quality, both for use in the Lancashire hearth and for making high quality steel in the open-hearth. On account of these good results the steel-works at Uddeholm and Domnarfvet, which are well supplied with water-power, soon installed electric furnaces in units up to 6000 kilowatts. Other works in Central Sweden were also interested in the new furnace, but long-drawn-out lawsuits with the Government as to the ownership of suitable waterfalls prevented any building operations before the war. Since then building costs have increased very much, and because of this, as well as on account of the depressed condition of our iron industry, it may be some time before more electric furnaces are built in Central Sweden.

Judging from several circumstances, it is likely that the production of electric pig-iron will develop, especially in the north of Sweden, where very cheap power is to be had and where there is a good supply of charcoal and iron ores suitable for this process. The bulk of the pig-iron used in the steelworks in Central Sweden will, however, most likely still be produced there in proximity to the steel furnaces in order to maintain the necessary control of its quality, and, as hitherto, the production of high grades of iron and steel will continue to be based on our appreciated ores in this part of the country. Lack of charcoal may perhaps promote the installation of electric furnaces instead of the old blast-furnaces.

The lump ore used in the electric furnace is charged unroasted, and must on this account be as free from sulphur as possible, especially as in this process less sulphur is taken up by the slag than in the ordinary blast-furnace. Briquettes and sinter are also used. A burden high in iron runs better than a burden lower in iron. This is the reason why the ores of Tuolluvaara, for example, which are high in iron and low in phosphorus and sulphur, are specially well adapted for this method. A pig-iron with relatively high silicon, 1 per cent. or more, is difficult to make, also pig-iron with high manganese. At one place, however, ordinary Swedish Bessemer pig-iron with about 3 per cent. manganese and 1 per cent. silicon is being produced, which is taken direct from the electric furnace to the Bessemer converter.

Owing to the low consumption of charcoal the phosphorus

content of the electric pig-iron is relatively low. Of the phosphorus in blast-furnace pig-iron 0·010 to 0·015 per cent. comes from the charcoal, but in electric iron only 0·005 per cent. A blast-furnace pig-iron with 0·020 per cent. phosphorus or less therefore demands specially pure ores and a careful sorting of the charcoal, but in an electric furnace there is no difficulty in getting a still lower phosphorus percentage using our ordinary steel-making ores.

Some Figures Relating to Electric Furnaces.

	The Experimental Furnace at Trollhättan.	Furnace of more Modern Design.
Interior height	10·8 metres	10·6 metres
Diameter of the hearth . .	4·0 „	5·3 „
Diameter of the shaft. . .	2·3 „	3·2 „
Volume of the smelting chamber .	12·5 m.³	35·0 m.³
Total volume	38·0 „	92·0 „
Kilowatts	about 2000	about 4000
Production per twenty-four hours	18 to 20 tons	„ 37 tons

Three 6000-kilowatt furnaces each produce about 55 tons of basic Bessemer pig-iron in twenty-four hours.

There are now fourteen electric furnaces in the country.

A modern coke blast-furnace with the necessary coke-ovens was started at Oxelösund in 1916. It is principally intended for the production of foundry iron for the home market. During the last few years there has also been produced some basic pig-iron, intended for the manufacture of cheap basic open-hearth steel, to compete with imported merchant steel.

Blast-Furnace Gas.—The blast-furnace gas, in excess of what was required for roasting kilns and hot-blast stoves, was formerly used mostly for raising steam for blowing engines, hoists, hammers, &c., but at isolated blast-furnace plants using water-power the excess gas was generally wasted. Since the beginning of the century the gas has also been used in open-hearth furnaces, briquette furnaces, and annealing furnaces. It has been proposed to use the excess gas for generating power direct, as in other countries, but in view of the development of our water-power and electric transmission it was found, as a rule, more advantageous to use the gas for heating purposes. There is only one place, Forsbacka, where gas-engines are used. Two Körting gas-engines,

each of 300 horse-power, with gas-washers and gas-holder, were erected in 1908 and have proved very satisfactory in every way.

The gas from the ordinary blast-furnace amounts to 3000 to 3500 cubic metres per ton of iron, with a calorific value of 1000 to 1100 calories per cubic metre, and in the open-hearth furnace it can replace up to about one-third of the fuel ordinarily used, mineral coal or wood. For keeping the furnaces hot over Sunday no other fuel is necessary. The absence of sulphur in this gas is naturally of importance for steel-making. A gas-holder is not used for this purpose, and the uneven flow of the gas is at some places regulated by a pressure-regulator, usually an Arca regulator. A fan is used for long-distance transmission of the gas, and in such cases the gas is washed to some extent by a water spray.

In most of the large steelworks efforts are now made to diminish the amount of gas used by the blast-furnace, mainly by improving the construction of the stoves, as already mentioned, so as to leave as large a surplus as possible for steel-making. It is also very suitable for annealing furnaces on account of its low pyrometric intensity as compared with producer-gas, and its transparent smokeless flame. The gas from the electric furnaces, being nearly free from nitrogen, has a calorific value of about 2200 calories per cubic metre, and about 500 cubic metres are obtained per ton of pig-iron. According to trials lately made, it can fully replace other fuel in the open-hearth furnace. But still better results are obtained if the gas is carburised by the injection of wood-tar with high-pressure steam, which gives a gas free from sulphur and equal in heating value to producer-gas from dry wood.

Production of Wrought Iron.

The output of wrought iron, which during the nineteenth century formed such an important branch of our iron industry, has certainly declined considerably during the last decades, notwithstanding the adoption of certain technical improvements in manufacture which have enabled it to hold its own in competition with soft open-hearth steel. This applies to the manufacture of Lancashire iron; the Walloon iron production shows no development of this kind, and is now reduced to a minimum.

The heavy manual work in the Lancashire hearth was greatly

lightened by the introduction in 1895 of the Y. Lagerwall mechanical rabbler, which also resulted in speeding up the process and reducing the oxidation losses. It further enabled the capacity of the hearth to be increased, and consequently the working of a bigger charge. This, as well as an improved construction of the heating apparatus for the blast, by which it could be more highly heated, has reduced the charcoal consumption. The increased production, together with reduced labour cost and lower charcoal consumption, due to these technical improvements, has certainly been of great economical importance for our Lancashire ironworks.

As long ago as 1885 some trials were made at one ironworks in refining molten pig-iron, charged direct from the blast-furnace into the Lancashire hearth. The method, however, was abandoned on account of the tendency of the hot metal to stick to the bottom of the hearth. Experiments of this kind were repeated later by C. W. Tideström, with more promising results. After some preliminary experiments about twenty years ago, using pig-iron remelted in a reverberatory furnace, extensive trials were again made in 1919 and the following years with the transference of the pig-iron direct from the blast-furnace. Although the question of the use of molten iron in the Lancashire hearth has not been definitely solved by these experiments, they seem to indicate that by this means the loss by oxidation in the hearth can be reduced to 7 or 8 per cent. as against about 11 per cent. using a cold pig-iron charge, and that the charcoal consumption may be reduced from 26 to about 15 hectolitres per ton. The quality of the iron has proved to be remarkably good. Moreover, it would seem possible, by the adoption of special arrangements and manipulations in connection with a molten charge, to work a pig-iron higher in silicon from the blast-furnace than has hitherto been used. According to earlier experience, this would give a finished iron of higher quality than when white pig-iron is used, due chiefly to the lower sulphur in a grey pig-iron.

Even though the market has shrunk considerably during recent years, the Swedish Lancashire iron still maintains its reputation as the purest and softest iron, unsurpassable in welding qualities, softness, and ductility. For ordinary forging purposes it has certainly, on the whole, been obliged to yield place to the

soft open-hearth steel, but when the very best welding material with a fine grain is required, as in chain forging, staybolts, &c., it still holds its special market. In the last decades the Lancashire iron has also been in good demand in the form of tube strips. Tubes of Lancashire iron have a stronger resistance to corrosion than steel tubes—at least, tubes of steel from coke pig-iron. Lancashire iron also finds a sale on account of its non-magnetic qualities and its low electrical resistance.

A considerable part of the Lancashire iron is still exported in the shape of rough bars for the manufacture of the very best crucible steel.

The greatly reduced demand for Lancashire iron has naturally brought about a cessation of its manufacture at some works. On the whole, we believe, however, that it will still always find a market, especially if the experiments made in recent years, with the object of cheapening the process without in any way risking the old good quality, should meet with final success.

Production of Steel.

The development of Swedish steel-making during the last twenty-five years is marked by the decline in the Bessemer process, whereas the open-hearth process has largely expanded and electric steel-making has come into use to some extent.

Bessemer.—No improvements worth mentioning have been made in the acid Bessemer process, probably because the pioneers of the process succeeded so well in perfecting it. The analysis of Bessemer pig is still the same—2·5 to 3 per cent. manganese and about 1 per cent. silicon—and no changes have been made in the weight of the charge, pressure of blast, or in manipulation. Everything is much the same as in 1870 to 1890, when the Bessemer process became fully established in Sweden.

In high-carbon Bessemer steel there was always a tendency for surface blowholes to form in the ingots, resulting in surface cracks in the blooms. These had to be removed by a hand chisel or by so-called "hammer-welding," that is, heating the steel to welding temperature with a flux of powdered sandstone or borax, and then hammering under a steam-hammer. Experiments made about 1890 proved, however, that these surface blowholes could

be prevented by a small addition of aluminium (about 0·01 to 0·02 per cent.). As this addition made no noticeable change in the quality of the steel, its use became general, and there was no longer the need for hammer-welding and but little chipping. To avoid piping, the ingots were provided with sufficiently large sink heads.

For Bessemer steel, of less than 0·50 per cent. carbon, there is now but little use, but the higher carbons have still an established market for different purposes. Bessemer steel is easily welded, is not very sensitive to overheating, and makes sharp cutting tools. It is used for welding steel, cutlery, solid and hollow drill steel, lathe tools, &c. Microscopic examination shows first-class Bessemer steel to be particularly free from slag inclusions, and compared with other steels the sulphur is very low, always less than 0·010 per cent.

The decrease in the use of Bessemer steel is partly due to the fact that open-hearth steel has proved better for many purposes, but the principal reason is that the cost of producing Bessemer steel has increased, on account of the greater charcoal consumption in the blast-furnace, more expensive ores, and greater waste in production. Owing to the small charges, there is also a larger amount of scrap in proportion to the weight of cropped ingots obtained.

The basic Bessemer process is only to be found at two works. The pig-iron is made from high-phosphorus ore from Grängesberg, with coke or charcoal as fuel. At one place the basic pig-iron is produced in an electric furnace, with good results. Only low-carbon steel is produced, which is used for merchant iron, building purposes, cheap wire rod, &c.

The Open-Hearth.—The open-hearth process was introduced in Sweden about ten years after G. F. Göransson in 1858 had technically solved the Bessemer process. The first furnaces were installed at works which formerly had produced wrought iron, *i.e.* "Lancashire iron," and at new works established on the Bessemer process. In the seventies and eighties both steel processes were used side by side at works making high quality steel in Värmland and Västmanland, but in Gestrikland and Dalarne the Bessemer process alone was used for high quality steel until well into the nineties. In the same period, at works which had not adopted

the Bessemer process, but were still chiefly engaged in the manufacture of wrought iron, the open-hearth was installed alongside the Lancashire hearth.

A strong point in favour of the open-hearth was that an outlet was found for the use of the high quality scrap from the Lancashire and Bessemer processes, which formerly was sold abroad, as a rule to England and America.

The first open-hearth furnaces in Sweden were small, a charge of 3 to 8 tons being generally used, and it was not until the early nineties that 10-ton furnaces were built. It was in the last years of the nineteenth century that the open-hearth process forced its way in our country. There was an increasing demand for soft steel, chiefly for tubes, because of the superiority of soft Swedish steel over steel from coke iron, when used in the new piercing processes, such as the Mannesmann. Bessemer steel proved too brittle, especially when cold-drawn to thin sections, and it soon became evident to Swedish steelworks interested in supplying such steel that open-hearth furnaces were necessary on account of the superior quality of open-hearth steel for this purpose. There was also a growing demand for steel of different qualities, both high and low carbon, and alloy steels, that could not be met by the Bessemer process, especially as the cost of production of Bessemer steel was rising. For these reasons works that had built up a technically and economically prosperous production based on the Bessemer process alone were compelled likewise to install the open-hearth process.

The choice then lay between the old acid method and the basic method, which was comparatively new. Most works adopted the basic process—partly because the demand was chiefly for soft steel, partly because it permitted the use of scrap bought in the open market. Up to this time the scrap was, however, mostly of Swedish origin, Lancashire or Bessemer, produced from charcoal iron. The Lancashire iron sold in the home market for forging purposes generally contained 0·06 to 0·07 per cent. phosphorus in order to make it easy to forge and weld. Remelted as scrap in the basic open-hearth it was possible to reduce its phosphorus to at least 0·03 per cent., which in Sweden is considered to be the maximum limit for phosphorus in open-hearth steel of ordinary quality. The phosphorus in the basic pig being somewhat higher

than in Bessemer pig permitted the continued use of Norberg, Stripa, Striberg, and other ores, which of old had been used for the production of wrought iron of the very best quality.

The number of open-hearth furnaces built, especially basic furnaces, increased rapidly during the nineties, and continued to increase up to the time of the war. This was especially the case at steelworks with a gradually declining market for Bessemer steel. In this connection experiments were made at many places in the production of high-carbon steel in a basic-lined furnace. But it soon became evident that the basic furnace was unsuitable for this purpose, even when using the purest raw materials, and an acid-lined open-hearth furnace had therefore to be used for high-carbon steels for which the Bessemer process was no longer good enough. The development of the production of high quality steel, both soft and hard, in our country has brought it about that, at present, some works use both the Bessemer, acid and basic open-hearth, or only Bessemer and acid open-hearth, some use only acid and basic open-hearth, and others only acid open-hearth.

As mentioned, it was possible at the beginning of the century to buy a very high-class scrap in the open market from which a high-class soft steel could be produced in the basic furnace. And the scrap from this soft steel, with suitable pig-iron, could be used in the acid furnace for the production of high-class carbon open-hearth steel, low in phosphorus and sulphur. But the scrap gradually declined in quality because of the increasing use of cheap open-hearth steel instead of Lancashire iron and the growing import of steel made from coke iron. The quality has declined so far that basic open-hearth scrap bought in the open market is no longer used for the production of high-class acid steel, and scrap from acid open-hearth steel has now to be used, the result of which is a relatively smaller production of high quality basic steel. A further reason for this decline is that there is now less demand for low-carbon high quality steel in the markets of the world.

Alongside of the works producing high quality steel are some whose only production is cheap soft steel for home consumption, in the form of merchant iron, reinforcing bars, structural iron, small angle-iron, and I-beams, sheet and wire rod, &c. They make also some medium hard steel for axles and forgings for

various purposes. These works produce their steel in basic open-hearth furnaces, using the cheaper grades of charcoal iron or coke iron, and scrap bought in the open market.

As already stated, the Swedish open-hearth furnaces at the beginning of the century had a capacity up to 10 tons, and there were very few furnaces that could handle a larger charge. The tendency has been towards larger furnaces, but not in the same degree as abroad. For furnaces with acid linings 15 tons is the maximum, and for basic furnaces 25 tons. The reason why acid furnaces do not take larger charges is the quality. Also for basic furnaces producing high-class steel 15 tons is rarely exceeded, while for cheaper material the limit of 25 tons is chosen solely for the ease of manipulation.

As to the furnaces, the hearth nowadays is made somewhat longer than formerly for the same size of charge. Through this the heat is more easily transmitted to the charge, and the oxidation is more rapid, which is of importance, because the small supply of scrap necessitates large amounts of pig-iron. A more rapid oxidation is also obtained by placing gas and air ports side by side, instead of the air ports above the gas ports. Less sulphur is also supposed to be taken up from the gas, when the ports are placed side by side, for the reason that the gas has been practically all burned before it comes in contact with the metal.

The only fuel used at first was wood or peat, made into gas in specially designed producers. Most of the water and tar was removed by a condenser. In the eighties it was, however, discovered by Odelstjerna that better results as to fuel consumption were obtained if no tar and steam were removed from the gas entering the open-hearth furnace, provided that the wood was air dried, *i.e.* did not contain more than 30 per cent. water. Later investigations have proved that the tar and steam react upon each other when heated to the temperature of the regenerators, and carbon is set free, which makes the flame luminous and promotes the transmission of heat to the bath. The consumption of wood is 2 to 3 cubic metres per ton of steel melted, depending on the kind of wood used and its content of water.

Because of the extended use of the open-hearth process, the supply of wood for fuel has proved insufficient, and there is an increasing use of mineral coal in the gas-producers, especially

for the basic open-hearth. A special Swedish type of coal-gas generator has been developed, known as the Tholander generator. It is cylindrical, 1·5 metres in diameter, with a circular step grate, and the blast enters at the centre, under the grate. At some works the blast is preheated up to 200° C. in an iron pipe recuperator placed in the chimney flue. This recuperator also furnishes the necessary steam from gradually injected pure water. Slagging is done by hand.

During the last years of the war, when practically all open-hearth furnaces in Sweden used wood fuel, the Tholander and the older producers of the same size could use wood without making any alterations, but the wood had to be cut into pieces not larger than 50 by 50 millimetres. In later years some revolving grate gas-producers have been installed, usually Rehmann.

The producers are, as a rule, placed close to the furnace, with one or two for each furnace. The flow of gas to the furnace is directed by the melter by regulating the air supplied to the producer.

In recent years charging machines have been installed for charging the furnaces, and modern electric overhead cranes are now always used for handling the ladle, moulds, and ingots.

Where quality steel is produced a cold charge is always used, which makes it possible to sort carefully the pig-iron and scrap suitable for the different kinds of steel made. The charge is tapped when the desired carbon has been reached. Recarburisation is not used. Additions of ferro-manganese, &c., are always made in the furnace, except for cheap steel, when the ferro may be added in the ladle. To ascertain the amount of carbon present, when working down, it was formerly necessary to use the forging test, and by overheating, quenching, and bending it was possible to ascertain the carbon present within 0·05 per cent., even when the carbon exceeded 1 per cent. At present the Enlund electric resistance method or the Malmberg magnetic method is used, each of which will give a very exact determination of carbon in a few minutes. It is possible by these means to follow the decarburisation of the bath, and the number of off-charges is thereby reduced to a minimum.

The steel is cast into ingots usually 250 by 300 millimetres in cross-section. In exceptional cases the dimensions 400 by 400

millimetres are used. A sink head is used for killed high-carbon steel, and this sink head is often provided with a circular groove, so that it can be broken off by a blow before the ingot is rolled. For the protection of the ingot moulds the very hot high-carbon steel is often poured through a tun-dish, placed under the nozzle of the steel ladle. This tun-dish is provided with one large hole or several smaller holes, dividing the stream of metal into several smaller streams. The ingot moulds are coated on the inside with tar, partly for the protection of the mould and partly in order to obtain by evaporation a protective covering of gas around the steel while pouring. By these precautions it is possible to get a high-carbon steel ingot without surface defects. Softer steel is poured direct from the ladle into the moulds, and any surface defects are removed by chipping. The moulds are used with the wide end up, so as to prevent the pipe from extending through the whole ingot. Bottom casting is in general used for plate-ingots, and ingots of low-carbon effervescing steel are cast narrow end up.

The increasing demands as to the quality of the steel and the increasing cost of production have necessitated unceasing attention to the pouring of the steel, both in regard to the surface of the ingots and their internal structure.

The Swedish production of steel castings has made great progress in the last quarter of a century. Both as to appearance and strength they are fully equal to any castings produced abroad.

Electric Steel.—The production of steel in electric furnaces has never attained importance in Sweden. We believe that, by means of the older methods for steel-making, we are able to produce a steel quite as good as any electric steel. But of course electric furnaces are in use for the production of some high-alloy steels that are difficult to produce in open-hearth furnaces. These are smaller than open-hearth furnaces, being of 1 to 4 tons capacity; usually they are electric arc furnaces of the Rennerfelt or Héroult type, but a few works use induction furnaces. All material is charged cold, except in one place, where there is a large electric furnace installed for refining basic Bessemer steel. This furnace has a capacity of 20 tons, and is fitted with four electrodes and a bottom connection.

Ferro-Alloys.—The production of ferro-alloys in electric

furnaces is relatively extensive. Several works produce ferro-silicon containing from 25 to over 90 per cent. silicon and ordinary silico-manganese. At one works there is produced 80 per cent. ferro-manganese almost free from silicon, and at another ferro-chromium with ordinary, as also with extremely low, carbon content.

Direct Methods.—It has already been mentioned that the only scrap now to be had for the production of high quality steel in the open-hearth furnace is the scrap from such steel. There is on this account a great scarcity of scrap at our high quality steel-works, especially where there is no Bessemer. The open-hearth furnaces have therefore to use a large percentage of charcoal pig-iron, necessitating large additions of ore in the furnace, and a longer time is needed for each charge. It is on that account natural that for a long time past we have taken an interest in all direct processes by which an iron sponge, suitable for open-hearth or electric furnaces, could be produced from ores high in iron.

The problem of producing a pure iron sponge from fine concentrates was solved at Höganäs about fifteen years ago. As raw material ore concentrates from Gellivare, containing more than 70 per cent. iron, about 0·015 per cent. phosphorus, and no sulphur, are used. Alternate layers of coal, lime, and ore are deposited in a refractory vessel, cylindrical in shape, and heated in a ring kiln up to about 1100° C. A very complete reduction takes place, and the finished product, in the shape of cakes, contains about 95 per cent. iron with small amounts of phosphorus and sulphur. The sponge has proved very suitable as scrap for the open-hearth, but is expensive, and has on this account not found much use for this purpose. If iron sponge is to be extensively used for steel-making, its price must be considerably lower than that of pig-iron.

Of the different methods now proposed for the production of iron sponge may be mentioned the Wiberg method, which, at the expense of Jernkontoret, is now being tried on a small scale at Sandviken. A shaft furnace is used, in which lump ore high in iron, such as Tuolluvaara, is reduced by carbon monoxide gas. The shaft has a rectangular cross-section, and the reducing gas is introduced on the long sides of the shaft at the bottom of the

furnace. Higher up, part of the gas, which now contains an increased amount of carbon dioxide, is withdrawn and returned to the two carburisers by means of a fan. The excess gas is burned in the upper part of the shaft and preheats the ore. In the carburisers the carbonic acid in the gas is reduced to carbon monoxide by charcoal, heated by means of two electrodes embedded in the charcoal.

The method proposed by Flodin is to produce fluid steel in an electric furnace, using briquettes made from an intimate mixture of iron ore concentrates, charcoal powder, and lime. Experiments have been made at Hagfors in a small furnace, and are now being continued in a large furnace on a commercial scale.

In the Edwin sponge iron process, now under test at Trondhjem, the high-tension flame arc, as used in the fixation of atmospheric nitrogen, is employed for the first time for producing iron.

The Mechanical Treatment of Iron and Steel.

Rolling-Mills.—The most prominent feature in the development of the rolling-mills during this century is the use of the electric motor for mill driving. The first three-phase alternating current motor was constructed by J. Wenström in the year 1890, and further improvements were made by E. Danielsson.

As early as 1894 there were two such motors installed at Boxholm—one a 70 horse-power motor as auxiliary for a rough bar-mill, and the other of 100 horse-power as auxiliary for a sheet-mill. Both mills had previously been driven by water turbines, which had proved to be inadequate. After this very successful installation there followed others of the same kind in rapid succession at Ramnäs, Hellefors, &c. The new mills built at Hofors in 1895—merchant-mill, bar-mill, and rod-mill—were entirely electrically driven. For each mill motor there was a separate generator, driven by a water turbine, at the power station 2 kilometres away. In 1899 electric energy was employed for the newly built rolling-mills at Horndal, using power transmitted from Näs at the Dalälven, a distance of 14 kilometres.

All these installations used three-phase induction motors, the later ones being equipped with a slip resistance placed in the rotor circuit, by means of which a speed variation could be

obtained, permitting a certain amount of energy to be stored in the flywheel during the pause between passes when rolling.

For bar-mills and wire rod-mills a much greater variation in speed, say from 1 to 1·5, was needed. It was on that account proposed that direct current motors should be used for finishing-mills, so as to obtain easily the different speeds required. However, A. Lindström, R. Dahlander, and E. Danielsson in 1899 had invented the multiple pole motor, and the cascade induction motor, by means of which it became possible to obtain different speed ranges. These solutions of the important problem gave a simple and comparatively cheap installation, without transforming the three-phase current to direct current or, as at Hofors, regulating the speed of the generator. If only two speeds are desired, one motor with multiple pole connection or tandem with cascade connection is used. For a number of speeds both the systems are used in combination, where as a rule the number of poles of the main motor is changed, and the secondary motor is provided with single winding. In this way it is possible to obtain four speed ranges—viz. two different speeds with the main motor alone, and two additional by connecting the secondary motor.

The tandem system with cascade connection was first used at Fagersta, where in 1900 a bar-mill and a wire rod-mill were equipped with electric drive, using energy from hydraulic power stations in the vicinity. Two years later five mills at Sandviken were electrified with 1600 kilowatts at 20,000 volts, transmitted from Näs, a distance of 55 kilometres. After transforming to 500 volts the power was used for driving three tube-mills, one bar-mill, and a universal mill. The tube-mills had ordinary three-phase induction motors with slip resistance; the other mills were equipped with the multiple pole system with cascade connection, resulting in three different speed ranges.

With those installations one may say that the use of the electric motor for rolling-mill driving was finally established in Sweden.

The animated debate as to alternating or direct current for rolling-mill driving resulted thus in favour of the former. Only at two places, Fagersta and Nykroppa, direct-current motors were installed for a wire rod-mill in 1902, and a few years later for a

bar-mill. During the first decade of this century electric motors were further installed at a number of our old rolling-mills, such as Hellefors, Surahammar, Forsbacka, Hallstahammar, Lesjöfors, &c., also at the new rolling-mills at Söderfors, Skogstorp, &c. For three-high mills, or other rolling-mills, where no speed ranges were necessary, there was used the ordinary induction motor with slip resistance. For other mills where variable speed was required, the cascade motors with multiple pole connection on the main motor were mostly used.

These motors proved economical also as to running expenses and maintenance, but the load factor was low, and at low speed the capacity for overload was small. Besides this there was loss of power through the slip resistance. For ironworks well supplied with cheap power this system is of advantage because of low installation costs, but where high price power has to be bought the large power loss may prevent its use. Because of the high price of power abroad, other systems have been worked out there by which the energy lost through slip resistance is put to useful work, and at the same time permits a more varying speed regulation than is possible with an alternating-current motor alone. It took, however, some time before anything similar was tried in Sweden. The first was the Krämer system of 1905, which in 1916 was installed at Långshyttan. Power was obtained from the just completed Government hydro-electric station at Älvkarleby, and the installation consisted of a 1000 horse-power alternating-current main motor, with a direct-current secondary motor on the same shaft, which was to be used for a wire rod-mill. The energy of the slip resistance was transformed to direct current in a rotary converter and then returned to the direct-current motor. At the highest speed the alternating-current motor alone is working, and lower speeds are obtained by varying the resistance in the shunt field of the direct-current motor. By these means the speed of the mill while rolling can be varied in the proportion 1 : 1·7, with an efficiency of about 90 per cent. and a load factor of nearly 1. This system has since been installed at several bar- and rod-mills.

In later years the now much improved direct current motor has been adopted at new mills because it permits a wide range of speed variation while rolling; besides, it gives an efficiency of 90 to 95 per cent. at all speeds.

For the transforming of alternating to direct current a motor generator is used, and mercury arc rectifiers are being discussed. The Leonard-Ilgner system is used for the reversing cogging-mills at two steelworks.

Electric motors are also used for all auxiliary machinery such as lifting tables, shears, saws, straightening machines, &c.

The use of the electric power at our rolling-mills has thus, up to 1915, been principally along the lines devised by experts of our own country, who have done so much for the development and improvement of the three-phase motor. Our ironworks, however, share with them the honour of having perfected the system of alternating current during the past quarter-century.

In connection with the use of electricity, more powerful motors were also installed at our rolling-mills, which permitted an increase of production through heavier draughts and larger billets.

The roll trains have also been strengthened in rebuilding new mills or remodelling old ones, and housings and bearings are constructed so as to permit of secure adjustment and rapid changing of the rolls, especially for merchant bar- and wire rod-mills, where the many different sections rolled necessitate frequent changing of the rolls.

At Hofors roller-bearings, made by Aktiebolaget Svenska Kullagerfabriken, are installed for the wire rod-mill. These bearings allow a more exact rolling because of practically no wear. Further, the power consumption is considerably reduced. This experiment has met with success. The roller-bearings, which have been in use since the beginning of 1925, seem to stand up well, and there is a saving of 35 to 40 per cent. in the power consumption. This makes it possible to make heavier draughts and to use larger billets.

Besides conversion to electric motor drive, the changes made at the cogging-mills, which as a rule are three-high, principally consist in improvements in handling the ingot when rolling. Whereas ten years ago lifting tables were used only for the first stand of rolls, and for the rest hand levers, there are now installed at most works stationary tilting tables or travelling tilting tables instead of the hand levers, while no change has been made as to the stationary lifting tables for the first stand. Stationary tilting tables are also used for the first stand of rolls at some few works

rolling ingots of smaller dimensions. Two cogging-mills, newly built, have travelling tilting tables for all the stands. The usual size of ingot is, as already stated, 250 by 300 millimetres, for which are used rolls 650 to 700 millimetres in diameter driven by an 800 horse-power motor, which permits of rolling in two stands at the same time.

For the wire rod-mill two stands of rolls are now used in the roughing-mill and seven to nine stands in the finishing train, in order to get a better distribution of the passes, and only one pass in each of the three or four last stands. By this a better adjustment is possible for those passes that affect the final size of the rod. At a couple of works this train is divided in two with a motor for each. The first train has then a lower speed and heavier draughts, and the second a lighter draught with gradually increasing speed due to the successively increased diameter of the rolls. For the roughing-mill the Schöpf oval repeater is used in some places.

The small quantities of each size generally required to be rolled in our bar-mills have induced some works to install double-duo mills in order to diminish the number of roll changes.

All plate-mills built during the last decades are, with one exception, two-high reversing mills. One mill built during the war is a three-high mill on the Lauth system. As to the sheet-mills, the only changes are heavier housings and larger roll necks than formerly.

For heating the iron and steel before rolling the Ekman coal-fired heating furnace is still used as improved before the end of last century. In some places gas-fired furnaces are used with a Bildt or Tholander producer, which is then placed close to the furnace. A central gas generating plant, supplying gas for several furnaces, is used in some places. The preheating chamber is nearly always provided with water-cooled pipe skids carried by brick walls, or, instead of pipes, heavy iron bars, so as to get a uniform heating without too much hand labour. In the heating chamber, which is kept of sufficient length, the steel is turned over by hand so as to get a uniform and thorough heating. The length of the furnace has been increased so as to get increased output and less fuel consumption.

The ingots are as a rule not rolled out direct, but are allowed

to cool and then reheated. At a couple of works, however, some steel is taken directly from the casting pit to soaking pits and then to the rolls.

It may further be stated that most of our rolling-mills are provided with the necessary modern machines and labour-saving appliances for straightening the steel, cooling, coiling, and bundling, &c.

Hammers and Forging Presses.—Forging presses, steam hydraulic as well as straight hydraulic, have in later years been installed for heavy forging. For less heavy forging the steam hammer is still in general use, and, for light forging, hammers driven by steam or by compressed air. For reasons of economy there is, however, a tendency to replace steam by hydraulic pressure or by compressed air. On this account there is no special interest in recovering heat from the waste gases for steam generation, except at such works which for the present desire to continue the use of steam for power. At one steelworks the Ruth steam accumulator is used with good results for storing steam from different sources for the use of forging and other purposes.

Cold-Working.—The cold-working of steel by drawing and cold-rolling is gradually progressing, both at the steelworks and at independent mills. The steelworks handle, as a rule, only high quality products, but the independent wire-drawing, as also the cold rolling-mills, largely manufacture cheap soft wire and cheap bands, using mostly imported raw materials.

Annealing of Steel.

During the last decade the question of steel annealing has become more important for the Swedish steelworks both in regard to carbon tool steel as well as special steels of different kinds. Different furnace builders have tried with more or less success to solve the by no means easy problem of constructing a suitable furnace, giving a uniform heat, easy to control and to regulate.

Steel castings and heavy forgings are annealed in a furnace with a movable bottom, running on wheels or on rollers. The furnace is fired at the end opposite to the door, or through the roof by means of Weardale burners. Lhe annealing is as a rule of a normalising character.

For soft annealing of rolled or forged bar steel, Hermansen furnaces are often used, more or less modified at different works. The steel is placed in a box of cast-iron or of non-oxidising cast steel, which material has proved very resistant, and is likely to replace cast-iron. The box is inserted in a muffle of firebrick, which is heated by gas jets in such a way that the flame from each jet travels around a section of the muffle, and in an opposite direction for every other section. The gases of combustion are collected in flues in the bottom of the muffle and then pass through a brick recuperator for heating the air for combustion. Coal or wood is used as fuel, and the gas generator, forming part of the furnace, is located at the middle of the furnace. If carefully attended to this annealing furnace gives a very uniform temperature.

As mentioned before, blast-furnace gas has been used for annealing during the past twenty years. Of the different types of annealing furnaces using the gas may here be mentioned a furnace where the annealing box is heated directly by the flame from a number of burners placed along the two long sides of the furnace. The gas enters horizontally through small openings, and the air vertically through corresponding openings at the spring of the roof arch. The burners are arranged in sections, with valves for regulating the gas and air for each section. The burning gas surrounds the box and the waste gases leave at the ends of the furnace through flues under the furnace bottom. The air is heated to about 200° C. in a simple and strongly built brick recuperator. This annealing furnace is cheap to build, easy to manage, and gives a very uniform temperature down to 600° C. It has been used with particularly good results at a couple of the larger steelworks. It is also easily arranged for normalising.

At one place an electric annealing furnace of American design has been installed. The steel is placed on a car, covered with a brick-lined hood and electrically heated by nichrome spirals embedded in the linings of the car and the hood. The furnace gives a uniform temperature, and is easy to handle because of the automatic regulation of the heat. It is likely to be specially used at works where blast-furnace gas is not available.

The annealing is controlled by the Brinell test. Surface decarburisation, which is difficult to avoid when soft annealing, is to a large extent prevented by the proper embedding of the

steel in cast-iron turnings or some other protecting material. It is now also usual to pickle the steel when it is essential to avoid decarburisation.

As far as we can judge the annealing at our steelworks is nowadays carried out in the very best way possible, principally thanks to the excellence of our annealing furnaces, which have been independently developed in Sweden, but also on account of our thorough experience in the practice of annealing itself.

Metallurgical Education, Official and Private Laboratories, and Institutions for Scientific Researches.

The Royal Technical University and the Elementary Mining Schools.

The engineering staffs of our iron and steel works have received their education at the Royal Technical University in Stockholm. There are two separate courses—one purely metallurgical, the other mechanical and metallurgical—each course covering four years. During the first years general subjects are studied—mathematics, physics, chemistry, mineralogy and geology, mechanics, electrotechnics, &c.; while the two last years are devoted to special subjects such as assaying, metallurgy, metallography, mechanical testing, mining mechanics, steelworks mechanics, &c. During the rebuilding of the University in 1917 ample room was provided for up-to-date metallurgical and metallographical laboratories, but because of the economic situation during later years their completion has unfortunately been delayed.

It may also be mentioned that we have mining schools at Falun and Filipstad where the pupils study for two years. These mining schools are intended for assistant engineers, analysts, draughtsmen, &c., and some practical experience and a certain amount of book knowledge is required for admission. Jernkontoret contributes to these mining schools two-fifths of the expense.

The Government Testing Institute.

In Sweden the importance of the introduction and use of rational methods for testing was realised at an early date. Thus

in 1875 a public testing laboratory for the mechanical testing of metals was established by Jernkontoret. The laboratory was built on the outskirts of Stockholm and was provided with an equipment up to date for that time.

Later this laboratory was enlarged to permit the testing of cement and bricks, but gradually the need of a larger and more modern testing laboratory was felt. In 1896 the original one was taken over by a new testing laboratory organised by the Government. It was attached to the Royal Technical University and placed under the supervision of the board of that institution. The new testing institution was, a few years later, not only equipped for the mechanical testing of metals, building materials, textile products, and materials for electrical purposes, but was also provided with a chemical laboratory for metals, fuel, &c. It was a distinct organisation from that intended for technical education.

There was, however, a rapid increase in the amount of testing required, and this finally necessitated a testing institution on a larger scale and independent of the Royal Technical University. Thus the Government Testing Institute in Stockholm came into existence and commenced operations in 1920. The total cost amounted to a little over 2 million Swedish crowns. The Institute consists of five separate departments and is particularly well equipped. It is intended not only for ordinary testing, but also to be of service to our industries in other respects, say in tracing faults in the course of manufacture or for investigating new methods. Through the united efforts of the Testing Institute and the industry (especially the iron industry), results of value to all concerned have been obtained.

The Testing Institute also undertakes inspection and checking tests for the control of deliveries, for buyer or seller, at home or abroad. The attention of members is also called to the scientific and technical research work in different branches carried on by this institution.

The Steelworks' own Laboratories.

When the Iron and Steel Institute visited Sweden in 1898 most steelworks had only a chemical laboratory for controlling the chemical composition of raw materials and finished products.

But few had a machine for making tensile tests, and the microscope was nowhere in use. Because of the increasing demands as to the quality of the steel, and especially on account of the increasing use of alloy steel, the old laboratories were found insufficient, and now practically all of our larger steelworks have established modern laboratories, where special care has been taken to provide a fully up-to-date metallographic department.

These laboratories enable the steelworks to control the manufacturing processes and the finished products, and they also facilitate extensive research work.

The Metallographic Institute.

During the world war the demand for special steels increased in a way that was never foreseen. As a consequence the increasing importance of scientific methods in the investigation of iron and steel became more and more recognised in Sweden. A special Institute of Metallography was therefore founded in Stockholm in 1921, for which purpose a fund was collected, to which severa of our most important steelworks and mechanical industries liberally contributed. Free accommodation for the new Institute was provided by the Government in the old School of Mines building.

The Institute, which is exceedingly well equipped in every way, has for its chief purpose the performance and advancement of metallographic research, but its object is also to assist the industry with more direct practical investigations "of scientific interest." It is meant to be a central institution especially for metallographic iron and steel research in Sweden, to which the laboratories of the different steelworks in the country could remit problems of wider scope, which might require for their solution more refined scientific resources.

The Royal Swedish Institute of Scientific Industrial Researches (Ingeniörsvetenskapsakademien).

This academy was founded in 1919, and has already proved itself to be of the very greatest importance.

Scientific researches have been made on various subjects and

with good results. Here we need only mention the researches made on the economisation of the heat, both within the industry and for domestic purposes.

The Academy is divided into seven sections, one of which is entirely devoted to metallurgy and mining.

Statistics.

It was not our intention to give any great amount of statistics in this paper. Nevertheless, a few figures are given below which we believe may be of some interest.

Production of Pig-Iron in Sweden during the Years 1823 *to* 1925.

Year. Yearly Average in—	Quantity of Pig-Iron Produced. Metric Tons. Yearly Average.	Quantity thereof Electrically Produced. Metric Tons. Yearly Average.	Number of Blast-Furnaces in Blast. Yearly Average.	Average per Blast-Furnace.		
				Quantity of Pig-Iron Produced. Metric Tons. Yearly Average.	Time in Blast; Days of 24 Hours. Yearly Average.	Average of Daily Production. Metric Tons.
1823–32	89,544	...	299	299	109	2·8
1833–35	97,680	...	224	436	151	2·88
1836–40	112,652	...	227	496	154	3·23
1841–45	117,796	...	221	533	144	3·70
1846–50	133,221	...	220	606	150	4·04
1851–55	154,347	...	229	674	143	4·73
1856–60	171,195	...	233	735	128	5·75
1861–65	204,826	...	222	923	138	6·68
1866–70	267,855	...	212	1,263	167	7·56
1871–75	332,456	...	215	1,546	188	8·20
1876–80	362,481	...	200	1,812	189	9·58
1881–85	429,377	...	186	2,308	224	10·28
1886–90	446,579	...	159	2,809	244	11·51
1891–95	471,147	...	150	3,141	254	12·35
1896–1900	517,795	...	141	3,672	275	13·33
1901–1905	528,255	...	135	3,913	266	14·69
1906–1910	567,418	263	120	4,728	270	17·51
1911–1915	692,977	23,448	117	5,923	288	20·54
1916	732,734	44,782	121	6,046	273	22·15
1917	828,969	67,059	124	6,611	291	22·72
1918	761,822	75,684	123	6,059	267	22·69
1919	493,701	64,470	97	5,022	227	22·12
1920	470,550	82,575	96	4,737	216	21·93
1921	314,378	64,016	69	4,498	180	24·99
1922	264,259	39,726	60	4,404	183	24·07
1923	282,607	56,288	77	3,616	166	21·78
1924	513,255	95,084	82	6,213	240	25·89
1925	431,988	87,237	75	5,717	210	27·22

Sweden's Production and Export of Iron and Steel, 1890 *to* 1925.

Year.	Quantity of Ingot Iron and Steel Produced.	Quantity of Wrought Iron Produced.	Total Production.	Total Export (including Manufacture).	Export as Percentage of Total Production of Rolled and Hammered Commercial Iron and Steel.[1]
					Per Cent.
1890	167,878	225,632	393,510	226,425	84·9
1895	197,177	188,726	385,903	221,317	84·6
1900	299,604	188,455	488,059	221,419	67·8
1905	368,198	182,640	550,838	267,240	71·4
1910	472,249	151,713	623,962	280,495	66·2
1913	590,887	158,472	749,359	303,092	59·6
1914	507,332	116,074	623,406	218,744	51·6
1915	600,418	119,629	720,047	307,417	62·8
1916	614,111	119,156	733,267	341,673	67·3
1917	581,000	114,426	695,426	256,397	54·3
1918	545,499	92,823	638,322	215,270	49·6
1919	491,266	63,629	554,895	177,019	47·0
1920	437,474	60,516	497,990	162,473	48·0
1921	211,602	24,352	235,954	62,451	38·9
1922	311,033	39,824	350,857	114,972	48·1
1923	270,680	38,970	309,650	114,653	54·6
1924	500,942	48,976	549,918	167,724	44·9
1925	475,100 [2]	42,900 [2]	518,000 [2]	165,574	47·0

[1] These figures are calculated from "total production," using the average of commercial products produced from ingots and wrought iron blooms during the period 1913 to 1925.
[2] Preliminary figures.

The Market for Swedish Iron and Steel.

In ancient times the markets of practically the whole world were open for our iron products, and the extent of sales under normal market conditions depended rather on the producing capacity of the Swedish works than on the different markets' inclination to buy. And the producing capacity was to some extent limited for long periods on account of governmental restrictions, made with the laudable intention of diminishing competition between the works themselves. Thus restrictions were imposed as to the buying of charcoal, whereby each works was prevented from buying outside a certain territory.

But there were also restrictions in other respects. Not only was it necessary to obtain a licence from the Government before

a new ironworks could be built, but it was necessary besides, in the old days, to apply for a special permit for the enlargement of any existing works, say, by erecting another hammer. With the introduction of the puddling process and, perhaps still more, the basic processes the Swedish iron industry, however, entered a new phase.

As regards ordinary merchant iron the world-markets became independent of the expensive Swedish iron as early as the beginning of the nineteenth century, and from that time Swedish wrought iron was only bought for more delicate purposes, or in case it was likely to be handled by ignorant blacksmiths, and for this reason had to be "fool-proof." Swedish Lancashire iron still possesses this last-named peculiar and special quality, for which reason it still finds buyers in many markets. Apart from this, as is well known, both basic Bessemer and basic open-hearth have replaced the Swedish Lancashire for forging purposes.

The Swedish Lancashire has, however, another special property which still puts it in a separate class, and that is its resistance to corrosion. Further, it is noted for its extremely high welding capacity.

From the time when methods for manufacturing high-class steel were introduced, the Swedish Lancashire and Walloon irons found extended use as remelting stock, especially in England and Germany. But in this respect there has been a great falling off, especially since the introduction of the electric furnace and its continued improvement.

It is, however, pleasing to us in Sweden to have discovered that it is unlikely that our customers abroad can entirely dispense with the pure Swedish remelting materials. It is obviously not only the absence of impurities such as sulphur and phosphorus that determines the final quality of the steel, but first and foremost the iron ore and the quality of the pig-iron made from it. One of the most prominent manufacturers of high-class steel in Germany expressed his opinion in this matter lately by saying, "We have finally found and proved the impossibility of making steel of the highest quality out of margarine."

It thus seems as if the old English belief in the presence of "body" in the steel is founded on real facts. It may possibly interest this honourable assembly to learn that the lately deceased

world-renowned metallurgist, J. A. Brinell, for a period of about ten years no longer believed in " body in steel," the idea of which, as a matter of fact, many consider antiquated, but that in later years he reverted to his earlier standpoint.

A very severe blow was dealt to the Swedish iron industry by the resolution at Versailles as to the limitation of armaments. This blow was felt most by our blast-furnaces not connected with steelworks, which lost most of their foreign customers, especially in England, but in other countries as well. To find new markets has up to now proved difficult, and the result is that the export of pig-iron is now only a small proportion of what it was before the war. And it is too early to judge if any change for the better is to be expected.

As for the market conditions for Swedish steel, we wish to remark that in the first place in Sweden, as is the case in England, Germany, and other countries, a distinction has to be drawn between works that produce steel products of *highest* quality, and such works that produce steel of *ordinary* quality intended for building purposes, heavy machinery of different kinds, simple forgings, shipbuilding, or similar purposes.

Practically, Sweden has never had an export trade in steel of such ordinary quality, and our steelworks making such material have had to depend entirely on the home market, which was satisfactory up to the end of the war, in spite of competition from other countries that have the happy advantage of suitable and cheap fossil fuel. Their advantage in that respect was to some extent counterbalanced by our comparatively cheap ores, so that we, with the help of a moderately protective tariff, have been able to find a steady and profitable sale for our products in the home market.

These conditions have unfortunately changed very much since the end of the war, and the import of rolled steel products has increased to an alarming extent. The difficulties commenced with the depreciation and final annihilation of the German monetary standard. A change for the better was expected as soon as that currency had been stabilised, but in this we were disappointed, and we are sorry to have to state that the situation of the Swedish steelworks which depend on the home market is still very serious.

The circumstance that the cost of production of Swedish steel is so high is due in the first place to the lack of fossil fuel. But we are also in a worse position than several competing countries on account of the eight-hour law of 1920. Thorough investigations have plainly shown that this law has brought about a considerable increase in the cost of all products of our iron industry.

A change for the worse is also to be found in the high freights now charged by our railroads as compared with those of several other countries, for instance Germany and Belgium. And in such a long and narrow country as Sweden the freight rates are of vital importance, especially for the charcoal.

It may also be mentioned that, despite all the repeated efforts of Jernkontoret, we have not succeeded in obtaining higher import duties on iron and steel. Our duties are the same as before the war, in spite of the decreased buying power of money, and because of this the import duty is in reality less protective now than formerly, and any change in this is hardly to be hoped for in the near future.

We must also call attention to the fact that a cheaper production is made more difficult, because the limited home market prevents us from building large, modern rolling-mills. Thus, for instance, ten days' rolling would be sufficient for America's largest rail mill to supply all the rails Sweden would need in a whole year. And exportation is not to be thought of except in very rare cases. Notwithstanding all these difficulties we should carry on fairly well, were it not that Sweden has become such a choice ground for dumping, especially from Europe.

Works that produce high quality steel, which of course have their principal market abroad, have less difficulty in placing their products than the works previously mentioned. But the exporting works also have their troubles.

This is in the first place due to the fact that the purchasing power to-day is less in many of our important markets than it was before the war, and in some markets there is hardly any purchasing power at all. But another reason lies in the progress in metallurgy during the last decade, and in the fact that our customers have acquired greater skill in the treatment of the steel. Where formerly Swedish steel had to be bought for high-

class steel manufacture, it is now in many cases possible to use a cheaper steel of lower quality. Either Swedish steel must be sold at prices that do not allow any profit for the maker, or else a cheaper steel from somewhere else is bought.

It is also due to the present depression that the Swedish steelworks which formerly sold their ingots or billets to steelworks in other countries, especially England and Germany, now try to get into direct contact with the individual consumers in those countries, selling them steel products rolled or forged to the desired dimensions. In many cases it proved impossible to carry on a paying business otherwise. This has naturally had a disturbing influence on old connections. How these matters will finally adjust themselves it is as yet too early to judge, but it looks as if it will never again be quite the same as before the war.

The same kind of symptoms are observable in the way the very selling is organised. There was a time when nearly all our export was in the hands of exporting houses, which also often advanced capital to the works. This rather questionable arrangement originated long ago, when the banking business was less developed, and when indeed there was much less need of money than there is to-day. All this is now changed, and our works try to get into direct contact with their customers in all markets. This is, by the way, absolutely necessary for purely technical reasons, which hardly require explanation here.

But what are the future prospects for our old renowned iron industry? As has been briefly stated, the present times are anything but satisfactory. Our industry has probably never been in such a critical situation as now, but, notwithstanding this lamentable fact, we expect and hope that our iron industry will not only survive but that it will expand so far as high quality production is concerned.

The prospect of once more building up a paying production of *ordinary* steel and iron depends on many things, and especially on whether we get a reasonably protective tariff or not. We call to mind that the wealthy United States protects its steel industry, which works under very favourable conditions, with an import duty of about 82 Swedish crowns per ton on ordinary merchant iron, while the corresponding Swedish import duty is 25 crowns,

or less than a third. A higher import duty in Sweden would seem reasonable and would improve the situation.

The best of all reasons for a more optimistic view as to the future of our special steel industry is that we believe, as already mentioned, that there is always likely to be an increased demand for high-class steel in the world, and for the production of such steel we are well fitted because of our pure and suitable iron ores, our charcoal supply and our cheap water power, which can be used both for producing mechanical energy and for metallurgical purposes.

Finally, we have our particularly well developed educational system for the training of our metallurgists, and with the help of the teachers and laboratories of our mining schools, as well as the Government Testing Institute, the Metallographic Institute, and last, but not least, Jernkontoret, we hope that our iron and steel industry will ever maintain a strong position in Sweden and still be respected all over the industrial world.

DISCUSSION.

The President reminded the members that the last occasion on which Mr. Wahlberg had delivered a paper to the Institute was in London in 1901, when he had disclosed to the Institute for the first time Brinell's method of testing for hardness, now a universally accepted method. The paper was published simultaneously in the Journal of Jernkontoret. He was sure it would be the desire of the members to record their thanks to the authors for an extremely interesting and valuable paper.

The resolution of thanks was carried with acclamation.

CORRESPONDENCE.

Professor Louis, M.A., D.Sc. (Vice-President), wrote that the paper had interested him greatly, not only on account of its value as an historical record, but because it covered practically the period during which he had himself been in touch with Swedish iron mining and metallurgy. In order that the historical details might be as accurate as possible, he would like to suggest to the authors that their statement that the first Gröndal briquetting furnace was erected at Bredsjö might be somewhat misleading. The first industrially working Gröndal briquetting plant was erected at Herräng in 1903, at which time he was consulting engineer to the Herräng Mines. About 1899 the concentration of ore was being attempted there by means of Monarch separators working dry, but those machines gave unsatisfactory results, and shortly after he had condemned them Gröndal submitted a new form of wet-working magnetic separator (his type III.), which, together with his tunnel briquetting furnace and ball-mill, appeared to solve the problem of treating a pyritic, low-grade magnetite ore. He (Professor Louis) believed that an experimental furnace and plant had been built at Pitkäranta in Finland, but he could not state that with certainty. Gröndal's methods and appliances were adopted at Herräng, and the plant was started in 1903, proving entirely successful. He (Professor Louis) described the entire plant in detail in the *Journal of the Iron and Steel Institute*, 1904, No. I. p. 40. It might also be put on record that the blast-furnace plant at Herräng was the first in the world to work, as it did for a while, on a burden of 100 per cent. briquettes. He was therefore justified in claiming that Herräng was the pioneer in that important method of utilising low-grade or pyritic magnetite ores, the principle of which had since then been so widely adopted.

In recounting the history of magnetic separation he would suggest that the name of Härdén, who was associated with Gröndal in much of his work, ought not to go unrecorded. He thought that the jigging or bumping boxes mentioned in Professor Petersson's paper were his invention.

He considered that the application of magnetic concentration was likely to be of increasing importance, even for the British iron industry. There was little doubt that the price of coke was likely to remain high, and it would be highly necessary for British ironmasters to cut down coke consumption per ton of pig to the lowest possible point. The most obvious way of obtaining that desideratum was by using richer ores, and possibly one of the readiest means of doing that would be by mixing with the ordinary ores a proportion of rich magnetic concentrates, and, if need be, sintering the mixture.

Professor Arvid Johansson wrote that Mr. Wahlberg and he were very much interested in Professor Louis's correspondence; he had thus given a much broader view of one of the many details in their paper than it was possible for them to do, considering that they had been able only to touch on quite a number of important and interesting questions bearing on the development of the Swedish iron and steel industry during the last quarter of a century. As regards the place where the Gröndal briquetting method was first adopted in Sweden, they feared, however, that Professor Louis's memory, otherwise so wonderful, had failed somewhat. Interest in trials of the briquetting method was aroused when some of the Swedish ironmasters visited Pitkäranta, in Finland, in the very beginning of this century, and the first result was that a briquetting plant was erected at Bredsjö in the year 1902, as stated in their paper and proved by the fact that Jernkontoret contributed 15,000 Swedish crowns to that plant, on condition that all works connected with Jernkontoret should, if they wished, have the right to have their ore concentrates tested at the plant. Several of the steelworks took advantage of that agreement, and, the results being favourable, further briquetting plants were soon built both at the mines and at the blast-furnaces themselves. The plant at Herräng, referred to by Professor Louis, might be characterised as a direct descendant of the plant at Bredsjö.

The furnace at Bredsjö was heated exclusively by blast-furnace gas, but it proved difficult to get the briquettes hard enough, when only that gas was used. On that account the later plants were fired either with coal producer-gas only or by producer-gas mixed with some gas from the blast-furnace.

SOME NOTES ON THE DEVELOPMENT OF THE SWEDISH MINING INDUSTRY DURING THE LAST TWENTY-FIVE YEARS.*

By WALFR. PETERSSON (Professor of Mining at the Royal School of Mines, Stockholm).

At the Meeting of the Iron and Steel Institute in Stockholm in 1898, Mr. G. Nordenström presented a paper entitled "The Most Prominent and Characteristic Features of Swedish Iron Ore Mining," in which he gave a general view of the standpoint of Swedish mining at that time. Since that time about a quarter of a century has elapsed, and naturally the Swedish mining industry has undergone considerable development from the technical as well as from the quantitative point of view. It is proposed in the following paper to present a short summary of the most notable events during this period. Moreover, the development of mining has been accompanied by a more thorough survey of the ore deposits with the aid of scientific methods, with the result that our knowledge of the iron ore resources of Sweden is much increased now both as regards the quantities available and the nature of the ores.

In the first place we will summarise what is now known regarding the iron ores in general.

The Swedish iron ore deposits occur, as will be remembered, principally within two separate districts, one in the central part of Sweden, known as Mellersta Sveriges Bergslager (mining district of Central Sweden), and one in the most northern region of the country, Lapland (see map, Fig. 1). In the former district, situated between the 59th and the 61st degrees of latitude and between the 14th and the 19th degrees longitude east of Greenwich, are the world-famed ore deposits of Dannemora and Grängesberg, and many other important deposits, such as Norberg, Riddarhyttan, Stripa, Stråssa, Striberg, Dalkarlsberg, Persberg,

* Received July 10, 1926.

Finnmossen, Nordmarken, &c. Outside of this area are some scattered ore deposits in the provinces of Södermanland and Östergötland, such as Kantorp and Nartorp. In the province of Småland the large body of titaniferous iron ore at Taberg is more generally known.

The Lapland ore deposits are mainly situated north of the Arctic circle within the parishes of Gellivare and Jukkasjärvi. The biggest deposits in this region are Kiirunavaara, Luossavaara, and Gellivare, famous for their considerable export of ore. Other deposits of great importance are Tuolluvaara, Svappavaara, Leviäniemi, Ekströmsberg, &c. In Lapland there also occur some extensive deposits of titaniferous ore at Ruoutevare and Wallatj.

All the iron ores referred to above are rich, and consist of magnetite or hæmatite or mixtures of both. They are more or less intimately mixed with quartz, limestone, or "skarn." The "skarn" or gangue consists of lime-magnesia-alumina-silicates, such as amphibole, pyroxene, garnet, chlorite, &c.

The phosphorus content of the Swedish iron ores varies considerably. A very large percentage contains only minute quantities, below 0·010 per cent., of this element, and these are the ores which form the principal raw material for the famous high quality Swedish iron and steel. The ores high in phosphorus are mostly exported. At the Kiirunavaara mines, for example, the export ores are classified according to the phosphorus content as follows:

Grade	A	with	less than 0·040 per cent. phosphorus		
,,	B	,,	0·040–0·10 per cent. phosphorus		
,,	C	,,	0·10 –0·60	,,	,,
,,	D	,,	0·60 –2·00	,,	,,
,,	G	,,	not less than 2·00 per cent. phosphorus		

The content of sulphur is comparatively low, as a rule well below 0·05 per cent. in those ores used in the Swedish iron industry. Most of the export ores are also unusually low in sulphur. The manganese content is likewise generally low, though some few thousand tons of ore containing about 10 per cent. of manganese are mined yearly, and with the few exceptions mentioned above, the ore deposits are practically free from or very low in titanium.

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FIG. 1.

Vanadium is not found in the titanium-free ores, but in those which contain titanium even in small quantities, vanadium is invariably found in quantities sometimes very small, sometimes up to about 0·2 per cent.

The percentage of iron in the Swedish rock ores is as a rule rather high, and this is specially the case with the Lapland ores. It has been estimated that the iron ores of Sweden contain on an average about 60 per cent. of iron, though all grades between 50 and 70 per cent. are found. For comparison it may be mentioned that the corresponding figure for the French minette ore is about 33 per cent., for the Lake Superior ores of the United States 51 to 52 per cent., undried, and for all British ores an average of about 30 per cent. In several mining fields there are obtained along with the rich ore varying quantities of ferriferous rock with too low a proportion of iron to be available for direct smelting. This ferriferous rock, which was formerly considered quite worthless, is nowadays in many mining fields subjected to concentration, whereby out of a raw material containing from 25 to 50 per cent. of iron a product called "slig" (concentrate) with an average of 60 to 71 per cent. of iron is obtained. As the concentrates are in the form of slime and thus hardly suitable for the blast-furnace process, they are converted at a number of works into briquettes, or are sintered.

Table I. contains analyses of some Swedish iron ores representing the above-mentioned groups; Table II. furnishes similar information concerning the concentrates previously referred to.

All the Swedish rock-ores belong to the pre-Cambrian formation of the earth's crust. The titaniferous ores occur exclusively in the form of basic segregations in gabbro rocks. The other iron ores occur as a rule as steeply dipping bed-, lens- or stock-formed masses, striking in conformity with the surrounding rock, either directly enclosed in these or surrounded by more or less thick masses of "skarn" or limestone. The iron ore deposits rarely occur isolated; as a rule there are several ore beds or lenses or ore stocks more or less close to each other, forming ore fields (*malmfält*) of greater or smaller extent.

The dimensions of the Swedish iron deposits vary within wide limits. In Central Sweden the width of the medium-sized deposits amounts to from 5 to 10 metres and the length to several hundred

metres. In the larger deposits the width of the ore-body in this part of the country is as much as 20 to 30 metres, and in two places, Grängesberg and Stråssa, they amount to as much as 90 and 110 metres respectively; and the respective lengths of the bodies are here 400 and 200 metres. A continuous body of ores occurs at Norberg with a length of 1200 metres and at Grängesberg with a length of 1000 metres. The whole series of ore-bodies, following each other in the direction of the strike (*malmstreck*), have, for example, a length of close on 20,000 metres at Norberg, of 4000 metres at Grängesberg, of 3500 metres at Riddarhyttan, and of 2000 metres at Dannemora.

The ore deposits of Lapland, as a rule, are more extensive than those of Central Sweden. Thus the ore deposit at Kiirunavaara has a width of 20 to 196 metres with a length of 3000 metres; at Gellivare there occur widths of up to 100 metres, and at Ekströmsberg widths of from 22 to 52 metres with lengths of 1200 metres. The *malmstreck* at Luossavaara-Kiirunavaara has a length of about 7500 metres, and the *malmstreck*, called "Stora malmen," at Gellivare has a length of 5000 metres.

The titaniferous ore beds are somewhat irregular in their occurrence; of the two above-named deposits of this kind the Taberg ore deposit has a length of 900 metres and a width of 360 metres, and Ruoutevare has a length of about 1600 metres and an average width of about 200 metres.

In addition to the rock ores there also occur in the youngest formation, the Quaternary, iron ores, but of a quite different type—namely, soft bog and lake ores, which, by the way, in many instances are still being formed in lakes and swamps. These deposits, which in older times played quite a considerable part in the Swedish iron industry, are nowadays employed in but very small quantities for the production of foundry pig-iron, principally in the districts of Jönköping and Kronoberg. In 1924 the total output of lake ore raised in Sweden was not more than 6358 tons, while 6,499,730 tons of rock ores were produced during the same year.

At the International Geological Congress in Stockholm in 1910 an estimate of the Swedish iron ore resources was made by the Swedish Geological Survey. Although these figures may not be considered perfectly accurate now, they are quoted

TABLE I.—*Representative Analyses of Lump Ores.*

		Norberg.			Riddarhyttan.		Dalkarlsberg.		Striberg.												
	Dannemora Mellanfältet.	Gamla Kolningsbergs-fältet.	Asgruvan.	Morbergsfältet.	Höjdgruvan.	Källfallet.	Djupgruvan.	Flintgruvan.	Kärrgruvan.	Asboberg.	Stripa.	Kantorp.	Persberg Storgruvan.	Finnmossen.	Taberg.	Grängesberg.	Gellivare C^1.	Gellivare C^2.	Kiirunavaara A.	Kiirunavaara C^1.	Kiirunavaara D.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Ferric oxide .	52·11	43·80	49·13	63·14	41·68	0·66	62·28	63·57	65·30	85·20	65·43	62·14	...	...	...	14·93	61·81	60·87	67·27	72·06	62·47
Magnetic oxide of iron .	...	...	...	...	...	79·66	...	...	...	...	...	...	66·90	78·50	72·57	68·95	...	...	...	...	...
Ferrous oxide	23·92	24·23	21·62	5·40	18·01	...	21·86	14·40	9·38	2·46	6·69	16·97	1·07	...	...	...	28·75	25·74	28·25	22·13	22·35
Manganese protoxide .	2·02	6·75	0·23	0·10	1·83	0·35	0·04	0·05	0·10	0·07	0·07	0·17	0·35	0·37	0·34	0·15	0·10	0·14	0·19	0·09	0·19
Magnesia .	6·15	4·71	5·59	1·46	5·99	5·08	4·12	5·04	0·57	0·81	1·60	1·80	4·48	4·58	4·90	1·42	1·47	1·43	1·15	0·78	1·26
Lime . .	4·35	2·72	8·01	2·06	5·01	0·30	0·92	2·39	0·60	2·34	1·52	0·25	7·34	3·34	4·38	4·31	1·90	3·36	0·68	1·13	5·98
Alumina .	0·43	1·11	0·20	0·84	2·29	1·32	1·58	2·57	0·40	2·77	0·73	2·36	4·00	2·26	1·96	1·43	0·91	1·00	0·37	0·45	0·43
Titanic acid .	...	...	...	...	...	...	...	...	...	...	...	0·25	...	...	...	...	...	...	...	...	...
Silica . .	6·39	4·55	14·95	26·88	25·20	11·90	8·28	11·44	23·66	6·45	23·58	15·86	15·08	8·28	12·98	5·68	4·03	5·24	1·48	1·92	2·29
Phosphoric acid . .	0·005	0·005	0·021	0·051	0·007	0·012	0·069	0·15	0·031	0·057	0·016	0·069	0·007	0·009	0·009	2·34	0·657	2·03	0·05	0·676	4·28
Sulphur .	0·029	0·023	0·024	0·005	0·083	0·033	0·006	0·008	0·004	0·006	0·009	0·005	0·018	0·02	0·021	0·006	0·028	0·047	0·016	0·011	0·019
Copper . .	0·002	...	...	...	...	0·003	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Loss on ignition	4·50	12·06	0·12	0·15	...	0·40	0·44	0·58	0·30	0·52	0·10	0·06	0·84	2·18	2·21	...	...	...	...	...	...
Arsenic . .	0·010	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
	99·916	100·158	99·895	100·086	100·100	99·718	99·595	100·198	100·345	100·683	99·745	99·934	100·085	99·539	99·370	99·916	99·655	99·857	99·456	99·257	99·269
Iron . .	55·0	49·5	51·2	48·4	43·18	58·20	60·6	55·7	52·95	61·50	51·0	56·7	49·20	56·76	52·47	60·33	65·58	62·58	69·00	67·60	61·06
Phosphorus .	0·0025	0·0025	0·009	0·022	0·003	0·005	0·030	0·065	0·014	0·025	0·007	0·030	0·0025	0·004	0·004	1·02	0·287	0·888	0·018	0·295	1·87

TABLE II.—*Representative Analyses of Concentrates.*

	Dannemora.	Norberg.		Magnetic Concentrate. Östanmossverket.	Riddarhyttan.		Dalkarlsberg.		Striberg.		Stripa.		Kantorp.	Taberg.	Gellivare Concentrate.
		Magnetic Concentrate. Bålsjöverket.	Non-Magnetic Concentrate. Bålsjöverket.		Höjdgruvan.	Källfallet.	Magnetic Concentrate.	Non-Magnetic Concentrate.	High-Grade Concentrate.	Coarse Concentrate.	Magnetic Concentrate.	Non-Magnetic Concentrate.			
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
Ferric oxide	...	63·71	86·71	60·71	61·10	61·74	68·29	90·90	83·60	74·75	30·30	88·41	69·57	57·71	67·50
Magnetic oxide (Fe_3O_4)	74·98	...	...	...	...	...	...	...	...	...	56·93	...	...	...	...
Ferrous oxide	1·41	25·48	3·05	25·26	28·77	27·95	23·66	2·57	5·91	6·74	...	3·76	20·31	26·61	30·12
Manganese protoxide	2·20	0·16	0·15	0·17	0·61	0·18	0·04	0·02	0·05	0·06	0·26	0·13	0·14	0·71	0·08
Magnesia	5·08	1·27	0·81	2·99	1·30	2·40	2·14	1·21	0·54	0·63	0·47	0·33	1·21	3·91	0·42
Lime	3·97	1·06	2·32	3·24	1·37	0·42	0·36	0·88	0·40	0·66	1·08	1·52	0·26	3·58	0·38
Alumina	0·64	0·15	0·30	0·09	0·85	1·08	0·98	1·70	1·05	1·31	0·75	0·97	1·72	1·20	0·60
Titanic acid	...	...	...	...	0·05	...	...	...	...	...	...	...	0·53	...	...
Silica	8·18	8·32	6·66	7·20	5·64	5·82	4·38	2·80	8·19	15·56	10·89	4·56	6·54	6·30	0·58
Phosphoric acid	0·011	0·018	0·032	0·008	0·007	0·007	0·030	0·144	0·025	0·039	0·009	0·008	0·055	0·011	0·039
Sulphur	0·081	0·006	0·026	0·033	0·172	0·049	0·005	0·051	0·015	0·009	0·011	0·018	0·016	0·036	...
Copper	...	...	...	...	0·004	...	...	...	...	...	...	...	...	...	...
Loss on ignition	3·28	0·22	0·14	0·18	...	...	0·34	0·36	0·30	0·36	...	...	...	...	...
	99·812	100·394	100·198	100·081	99·873	99·646	100·225	100·635	100·080	100·115	100·700	99·706	100·351	100·067	99·730
Iron	55·4	64·4	63·1	62·1	65·15	65·06	66·2	65·55	63·10	57·60	62·56	64·96	64·5	61·07	70·62
Phosphorus	0·005	0·008	0·014	0·0035	0·003	0·003	0·013	0·063	0·011	0·017	0·004	0·0037	0·024	0·005	0·017

below as representing a minimum of what is certainly available. It should be noted that wherever more extensive investigations have been made since the date of this estimate, these have invariably indicated a considerably larger amount of ore.

Locality.	Actual Supplies.		Potential Supplies.	
	Lump Ore.	Concentrating Ore.	Lump Ore.	Concentrating Ore.
	Million Tons.			
Northern Sweden	1035	670	134	80
Central and Southern Sweden	143	70	90	25
Total . . .	1178	740	224	105

The iron mines are, as a rule, not very deep. The largest of all, namely, Kiirunavaara, is still mainly in the quarrying stage. The deepest level at which mining is now carried on in Swedish iron ore mines is about 400 metres below the outcrop of the ore. In none of these places does the ore differ in composition from that of higher levels, nor has it been found as a rule that the dimensions of the ore deposit decrease with increasing depth. On the other hand, a number of minor deposits have pinched out at comparatively small depths.

In a number of deposits, particularly in Lapland, diamond drill holes have been put down in order to investigate the depth of the deposit.

The most extensive research works up to this time are those which have been carried out in Grängesberg, Gellivare, and Kiirunavaara, the ore fields from which come most of the Swedish export ores. In the Grängesberg export field, for exploration purposes, 2603 metres of drifts and crosscuts have been run, and 3045 metres of diamond drill holes put in, 500 metres below the surface, proving that the Grängesberg deposits of phosphoric ore are larger in extent at a depth of 500 metres than at higher levels. At Gellivare extensive surveys by diamond drilling have proved that the widths of the ore in different parts of the field are the same as on the surface down to a depth of 562 metres, and that the quality of the ore at this depth is unchanged.

At Kiirunavaara very extensive bore-hole surveys (the total length of bore being 14,033 metres) have also shown that the dimensions of the ore-body do not diminish at the depth reached by the drills, varying from 400 to 900 metres below the top of the mountain. This survey has further yielded the somewhat surprising result that whereas the ore at the higher levels is chiefly highly phosphoric, deeper down it is to a great extent very low in phosphorus, in places as low as 0·002 per cent., and at the same time very rich in iron (67·9 to 69·5 per cent.). There also occurs, however, in the deeper part of the deposit, phosphoric ore of the same character as that which has always been mined in Kiirunavaara, but generally well separated from the ore low in phosphorus.

Output of Iron Ore.

The annual output of lump ore and concentrates, except bog and lake ores, is shown in the following table :

Period.	Tons per Year, Average.
1833–1840	235,000
1841–1850	270,000
1851–1860	349,000
1861–1870	489,061
1871–1880	760,987
1881–1890	904,939
1891–1900	1,907,043
1901–1910	4,095,479
1911–1915	6,749,091
1916–1920	5,865,471
1921–1924	6,188,373

From 1902 on, the figures include a relatively small proportion of purple ore and purple ore briquettes mainly from Norwegian pyrites.

The year 1833 is the first for which official statistics are available. With a fair degree of exactitude the total production of iron ore in Sweden up to 1924 inclusive has been calculated at about 210,000,000 tons. The annual output passed the first one million mark in 1892, the second in 1896, and the third in 1904. The maximum production, so far, has been close to 7·5 million tons in 1913. After a depression during and after

the Great War the production curve is now ascending. In 1925 the output of lump ore and concentrates together was 8,168,346 tons.

The present producing capacity of the Swedish iron mines and concentrating plants that are fully developed and equipped is, however, far in excess of the actual output. The annual capacity is at present about 10,585,000 tons of lump ore and about 1,227,500 tons of concentrates, making a total of about 11,812,500 tons. This corresponds in round figures to about 7,500,000 tons of pure iron. Out of the total, in 1,773,300 tons of ore the phosphorus content is below 0·005 per cent., in 603,200 tons 0·006 to 0·010 per cent., in 2,237,500 tons between 0·011 and 0·06 per cent., in 1,559,400 tons between 0·061 and 0·8 per cent., and in 5,639,100 tons more than 0·8 per cent.

From these figures it is evident that the Swedish iron mining industry could easily meet a demand for a much higher production than that which corresponds to the present consumption.

Until 1857 the export of Swedish iron ore was prohibited, except for a small annual amount to Finland, which country, after the separation from Sweden, still had to rely mainly on Swedish ores for its comparatively small requirements. An export duty was imposed in 1857, but was removed in 1864, from which time the export has been free of duty. It was twenty years, however, before the export began to increase noticeably. The amount in 1886 was only about 20,000 tons, but the following year the export from the Grängesberg mines commenced. The export tonnage of the country exceeded 100,000 tons in 1888, 1 million tons in 1896, 2 millions in 1903, 3 millions in 1904, 4 millions in 1910, 5 millions in 1911, 6 millions in 1913, and was 8,800,366 tons in 1925.

The rapid increase was mainly due to the opening-up of the big deposits in Lapland, where Gellivare began shipping in 1892 and Kiirunavaara in 1902. Other important export fields are Blötberget, Idkerberget, Lekomberg, Stråssa, Norberg, Kantorp, &c.

Nearly all the ore from Kiirunavaara, Luossavaara, and Tuolluvaara is directed through the port of Narvik on the Atlantic in Norway, to which place the distance from Kiirunavaara is 173 kilometres. The ore from Gellivare and a small part of that from the above-mentioned mines is sent through Luleå, the port

at the head of the Baltic, the distance from the Gellivare mines being 211 kilometres. This port is closed by ice five to six months of the year, while Narvik is open practically the whole year.

The ore from Grängesberg and several other mining fields in Central Sweden is transported via Oxelösund; Stockholm and Gävle also are important centres for ore shipment.

Mining Practice in Swedish Mines.

Breaking Ground: Boring and Blasting.—As stated in the above-mentioned paper by Mr. Nordenström, hand-drilling was practically the only method of boring in Swedish mines about twenty-five years ago. Rock-drilling machines of the heavy piston type were, however, introduced, and electrical rock-drills of the Siemens and Halske and the Marwin type have been tried. These air-drilling machines were very heavy and needed two men to operate them, and they worked with an air-pressure of 3 to 4 atmospheres. These machines gave a somewhat greater drilling speed than hand-drilling in overhand workings, but in stoping the effect was so little better than hand-drilling that, as a rule, the cost of erecting a plant for machine drilling was not considered advantageous.

A great change in these conditions occurred when, about 1902, air-pressures of 6 to 7 atmospheres began to be used, whereby a very great increase (2·5 to 3·5 metres) was obtained in the depth of holes drilled by one man per shift.

About the same time a new type of rock-drill, the so-called "Baby" machine, was introduced. This machine was also of the piston type, but considerably lighter and more easily handled, and could be operated by one man only. These two changes brought about a radical alteration in the relations between machine- and hand-drilling.

A still more radical change was, however, brought about by the introduction of the light rock-drills, the so-called hammer type with hollow drills, through which water or compressed air was forced in order to keep the bottom of the holes free from rock powder (Fig. 2, Plate V.). The first hammer rock-drill (a Water Leyner machine) was tested in Sweden in 1904, and as such machines, specially adapted for the conditions in the Swedish mines, have been designed, the hammer drills have practically

completely superseded the piston machines, and hand-drilling is now hardly practised at all in Swedish mines. The types of rock-drills now in use are mostly of Swedish make (Nya A.B. Atlas). Also the machines used at the mines for sharpening the drills, and the compressors are practically exclusively of Swedish make (Atlas Co.).

The above-mentioned electric machines of the types Marwin, Siemens and Halske, &c., have not been found suitable for the Swedish mines, and are at present not in use, being much inferior to the modern compressed air-drills.

As an example of the fundamental importance of the development of the rock-drilling machine for mining, the following may be quoted.

At a quarry in the north of Sweden there was drilled as an average per year:

By hand	4·89 metres per man per shift
With 70-millimetre piston machines .	5·19 ,, ,, ,,
With hammer machines . . .	16·90 ,, ,, ,,

In an overhand stoping mine there was drilled:

By hand	2·81 metres per man per shift
With 70-millimetre piston machines .	3·6 ,, ,, ,,
With hammer machines . . .	11·7 ,, ,, ,,

In other words, one man drilled with the help of the hammer machine in the former case 3·5, and in the latter case more than four times as much per shift as by hand. The cost of drilling by hand in the quarry was about 50 per cent., and overhand about 100 per cent., more than in drilling by hammer machine.

Explosives.—The explosive almost exclusively used in the Swedish ore mines is gelatine dynamite; in recent years chlorate and perchlorate explosives of Swedish make, named Territ and Carlsonit, have also been used to some, though rather small, extent. During the war some experiments were made with Marsit (liquid oxygen), but this explosive is not now in use in Sweden.

Concerning the general effect of blasting in the Swedish mines, the amount of rock broken down at one blasting varies on an average between 8 and 15 tons, and, where circumstances are favourable, amounts to about 25 to 35 tons per kilogramme of the explosive.

Mining Methods.—The underhand stoping method was, until 1858, the only method of mining employed in Swedish ore mines; in that year overhand stoping with filling was introduced in the Åmmeberg zinc mines, but it was not till 1869 that the method began to be employed in a Swedish iron mine, namely, at Dalkarlsberg, after which it was gradually introduced into quite a number of mines. About 1900 the shrinkage stoping method was first adopted at Grängesberg and Striberg, and has since gradually obtained a very general application, having in many mines replaced the overhand stoping with filling process or the underhand stoping method. The crosscut method with filling (*tvärbrytning*) has been employed since the 'seventies in a number of mines with loose or readily crumbling ore; in the later years, however, this method has been replaced by the sub-level caving method. Also the block-caving system is adopted in some of the mines. The above methods are applied in notably the same manner as is usual in other countries.

In connection with the change to modern methods of mining and the increase of the production there has been an endeavour to centralise the mining as much as possible. In former times the shafts were generally placed in the ore itself, but nowadays they are as a rule placed in the country rock, and so far from the ore that they are undisturbed by any caving ground which may occur in the workings. They are placed with a view to serving several mines at the same time, the above-mentioned improvements in the drilling technique having brought it about that the driving of long drifts does not present such great difficulties as formerly. The arrangements for the loading and transport of the broken rock on underground tracks has undergone important improvements during recent years.

The loading of the broken rock underground, which by underhand stoping was carried out by hand, is in all new mining methods carried out automatically through chutes arranged in such a way above the floor of the drifts that the rock may run directly into the cars placed underneath. The transport underground is on tracks, hand transport being used for shorter distances and smaller quantities, and locomotives driven electrically or by compressed air for longer distances or larger quantities. For hoisting most of the mines have guide hoists or skips with a speed of 3 to 5 metres

per second. The transport of men is mostly effected by means of cages with safety arrangements.

For drainage the old types of lifting- and force-pumps driven by water-wheels or turbines have been replaced by more modern and efficient pumps, especially in the large mines. Electrically driven high-speed piston pumps and centrifugal pumps erected in underground machine-rooms are largely used (Fig. 3, Plate V.). For collecting the water large reservoirs are generally arranged in the neighbourhood of the pump-rooms. The flow of water in Swedish ore mines is as a rule rather slight, and only in isolated cases amounts to as much as 300 to 500 litres per minute.

Ventilation.—In by far the greater number of Swedish mines natural ventilation is sufficient. Where artificial ventilation is required, as in long drifts or in shafts, electrically driven centrifugal fans are generally employed, or else ventilation is provided by means of compressed air injectors.

Lighting.—The underground working faces are in most cases lighted by acetylene lamps. The main levels are often lighted by electric incandescent lamps. In the rock houses and other buildings either electric lamps or Lux lamps are employed. At the open cut works in the export fields electric incandescent lamps are used during the dark hours.

Shafts and Head Frames.—The shafts in Swedish mines are either vertical, which is the rule, or inclined, following the dip of the ore body. The older shafts are usually circular, with a cross-sectional area up to about 40 square metres. The more modern shafts in ore mines are rectangular, and have an area usually of not more than from 18 to 25 square metres, occasionally of only 10 square metres ; in the big export fields, on the other hand, they are considerably larger, with an area of up to 40 or 41 square metres.

The shaft-head frames are usually wooden, and are sometimes wholly or partially encased in wood, sometimes uncovered. More rarely, shaft-head frames are built of slag bricks or constructed entirely of iron. Fig. 4 (Plate VI.) shows the shaft-head frame at Källfallet, Riddarhyttan, which is completely encased in wood ; Fig. 5 (Plate VII.) illustrates the uncovered head frame at Konstängsgruvan, Dannemora ; while the slag brick-built head frame of the Central Shaft, Klackbergsfältet, is depicted in Fig. 6.

Ore Treatment.—In most of the smaller iron mines the separa-

tion of the valuable minerals from the waste material is carried out simply by hand-sorting and hand-picking in rock houses erected in the immediate neighbourhood of the shaft-head. The smalls (*syltan*) were formerly treated by washing and picking by hand.

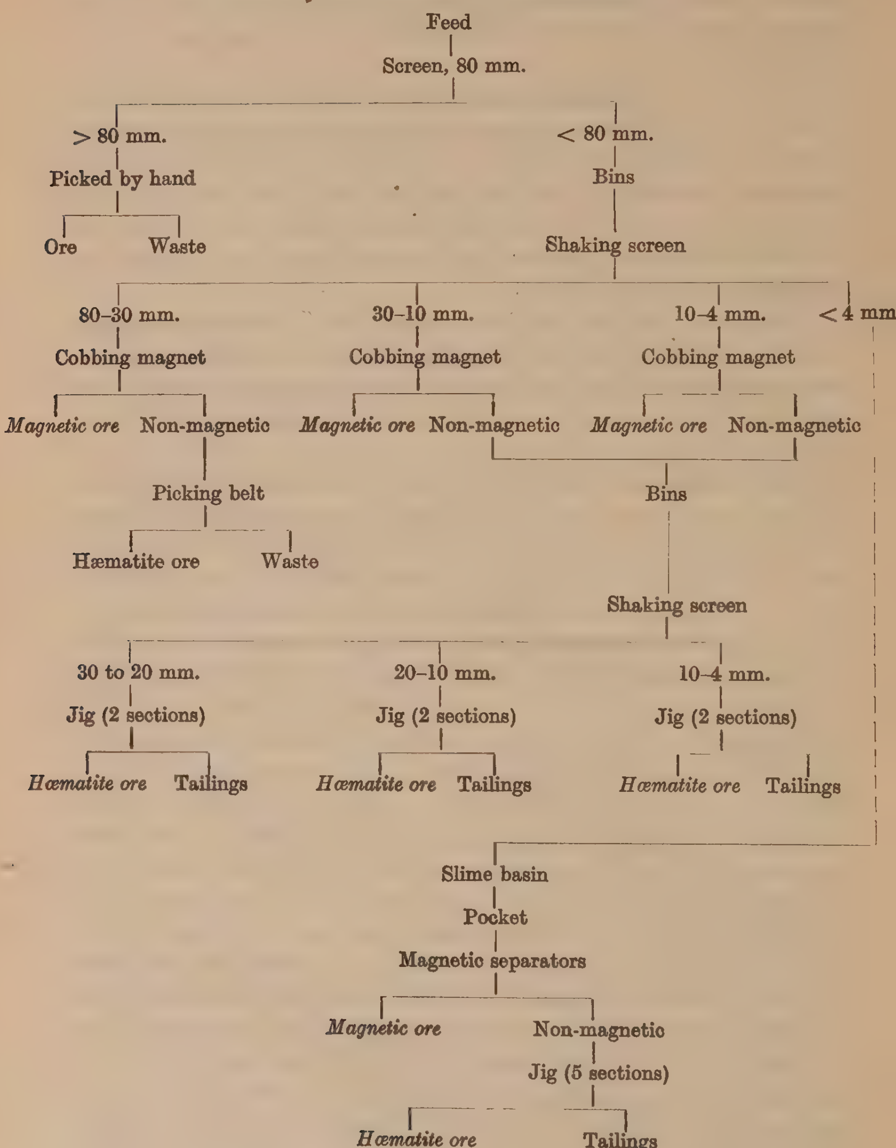
Since 1884, however, the washing process in most mines treating magnetic iron ore has been superseded by coarse separation with cobbing magnets (*malmskiljare*). Besides the Wenström ore separator, which was the first to be employed in 1884, several more modern coarse ore separators have come into use in recent years, such as the Landén-Josephson, the Vulcanus, the Gröndal, and several others.

At mines with magnetic ore mixed with hæmatite ores jigs are now commonly used for separating the hæmatite from the non-magnetic tailings coming from the magnetic separators. At such a mine the smalls are treated according to the flow-sheet given on the next page.

The magnetic separator for finely crushed material first used in Sweden was of a type called Monarch, constructed by Ball and Norton, and it was an Englishman, Mr. Porter, who first introduced it into Sweden in 1894. About the same time the Swede, Dr. G. Gröndal, constructed a magnetic separator which, unlike the Monarch separator, treated ore pulp. At the end of the 'nineties this separator, commonly called Gröndal-Dellwiks or Gröndal's Type I., was in use in a large number of Swedish concentrating works. Later a large number of separators constructed by Swedish engineers, such as Gröndal's Types II., III., IV., and V., the Lundberg-Holmberg, Fröding, Landén-Josephson, Salwén, Blötberget and the Allians, were more or less extensively used in a steadily increasing number of magnetic separating works. At present it is, however, chiefly Gröndal's Type V. and the Allians separators which are in use. Gröndal's separator Type V. consists of a brass drum rotating round a system of radially placed fixed electro-magnets with alternating polarity. The mass is supplied from underneath as a pulp, out of which the magnetic particles are drawn up to the drum on which they pass the different magnetic poles under a strong jet of water, and are finally discharged on the opposite side of the drum.

The Allians separator also consists of a brass drum rotating

Flow-Sheet for Coarse Iron Ore Separation.



round a system of radially placed fixed electro-magnets with alternating polarity. The mass suspended in water is carried to the drum under the magnets. The magnetic particles are attracted to the drum, and in order to remove the magnetic particles a "remover," placed horizontally and parallel to the axle of the drum, is used. This consists of an axle of wood with points of soft iron fixed radially therein. By means of a very powerful jet of water the magnetic concentrate is separated from adhering low magnetic substances.

It is common to run two or three such magnetic separators in series, and to regulate the magnetic power in the different separators so that the first separator produces a crude concentrate which is divided into concentrate and tailings in one or two of the following separators. In several cases a secondary crushing takes place between the first separator and the following ones. As an example of such an arrangement the following flow-sheet for a magnetic separating works is quoted:

- Raw material
  - Breaker (coarse crushing)
    - Cobbing magnet
      - Magnetic material
        - Ball-mill (fine crushing)
          - Magnetic separator
            - Crude concentrate
              - Tube-mill (fine grinding)
                - Magnetic separator
                  - Magnetic concentrate
                    - Magnetic separator
                      - High-grade concentrate
                      - Tailings
                  - Tailings
            - Tailings
      - Waste

For crushing the crude ore for concentrating purposes, crushers of the Blake type are principally used for the coarse crushing.

Ball-mills, chiefly of Gröndal's construction, are used for finer crushing and tube-mills for the finest crushing. Generally the magnetic substance and the gangue are so finely intermixed that very fine crushing is necessary to ensure a sufficiently rich concentrate.

The concentrate from the magnetic separation is always mixed with much water, and cannot on that account be directly used. Formerly it was necessary to store a concentrate for some time in order to get rid of part of the water. Nowadays at most of the concentrating works, so-called jigs (*skakskopor*) are used in which a concentrate suspended in water is allowed to settle. This jig consists of a box of sheet iron triangular in vertical section, hung on a hinge at one end and shaken rapidly by a simple cam acting against a tappet at the other end. The contents of the box are thus kept in rapid vibration, by which the concentrate is settled and the water expelled. The front end of the box is suspended on two chains, and may be raised or lowered more or less for removing the water expelled by the vibration. It is emptied through the lowering of the front end by means of the chains. The concentrate is then so packed that it must be removed by shovelling, and has a water content of about 6 to 7 per cent., just suitable for briquetting.

For hæmatite mixed ores concentrating tables of the Ferraris type are used. For sizing Ferraris' screens are now exclusively used.

Methods of Exploring for Ore.

As most of the Swedish iron ores contain magnetite, methods of discovering ore deposits by the deflection of a magnetic needle in the vicinity of magnetic ores have long been in use. In the middle of the eighteenth century the miner's compass (*gruvkompassen*) was constructed; with that simple instrument numerous ore deposits have been discovered in Sweden. However, in the 'sixties and 'seventies of the nineteenth century attempts were made to devise magnetic measuring instruments by means of which a more exact and more detailed knowledge of the magnetic conditions could be obtained. These endeavours resulted in the invention of the Thalén magnetometer (about 1870) for measuring magnetic horizontal intensity, as well as the Tiberg inclination balance (about 1880) and the Thomson-Thalén

FIG. 2.—Rock drill, type "Rex."

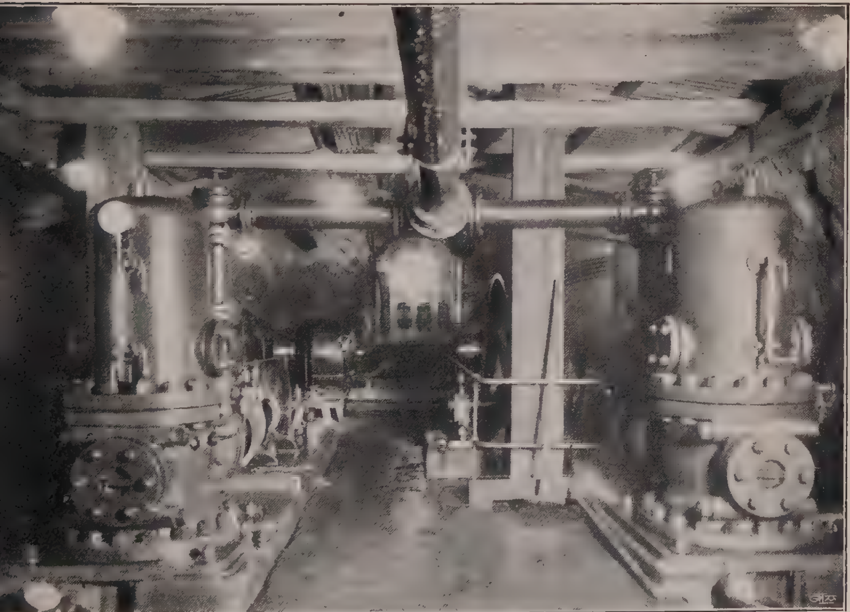


FIG. 3.—Underground machine-room, Blötberget.

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FIG. 4.—The shaft head-frame and concentrating plant at Källfallet, Riddarhyttan.

FIG. 5.—The shaft head-frame and coarse separation works at Konstängsgruvan, Dannemora.

FIG. 6.—The shaft head-frame and coarse separation works at the Central Shaft, Klackbergsfältet.

vertical force balance (1899) for measuring magnetic vertical intensity. The magnetic horizontal and vertical intensity maps of mining areas at the surface and the maps of the magnetic fields (*kraftpilkartor*) of mining areas underground, which have been drawn up with the aid of measurements made with these instruments, have greatly facilitated the work in Swedish iron mines. These Swedish methods have indeed been coming more and more into use abroad, and particularly in America.

Electrical Prospecting.

Since the introduction of the electrical ore-finding method of Daft and Williams in 1907 in Sweden, ore finding by electrical means has been the subject of a lively interest, and at present two Swedish ore-finding methods are worked out which have been largely used in Sweden as well as in foreign countries, especially in the U.S.A. and South Africa. One of these methods is based on the investigation of the potential in an electrical field by tracing equipotential curves or measuring differences in potential between different points—the potential method; the other method—the electromagnetic method—is based upon investigations of the direction and intensity of an electromagnetic field.

While the use of magnetic measurements is possible only for magnetite or magnetic pyrites, the electrical methods are suitable for all kinds of deposits which have an electrical conductivity different from that of the surrounding rock—that is, for practically all ore deposits. By means of the electrical ore-finding method large deposits of copper, pyrites, zinc and lead ores have, for instance, been detected in the north of Sweden in the neighbourhood of Skellefteå.

In addition to the magnetic and electric investigation methods, prospecting by means of diamond-drilling has been extensively resorted to in Swedish ore-districts. On account of the ease with which it is manipulated and the moderate cost at which boring can be carried out with it, the Croelius' diamond drill has been almost the sole make employed. With this machine a hole with a diameter of 35 millimetres right down to a depth of 609·84 metres, and another with a diameter of 55 to 45 millimetres and a depth of 847·1 metres, have been drilled, both in Kiirunavaara.

DISCUSSION.

Professor Henry Louis, M.A., D.Sc. (Vice-President), said he desired, in the first place, to compliment the authors of the various papers that had been read on the very excellent account they had given of mining and metallurgy in Sweden. So far as the present paper was concerned there were one or two points in which he was specially interested, and which he hoped the author would be good enough to amplify. Brief reference was made in the paper to shrinkage stoping or magazine mining. He had always been under the impression that that method, if not actually devised in Scandinavia, had been early adopted and very fully developed there. He had first seen it in operation at Åmmeberg and Grängesberg, perhaps fifteen or more years ago; he would like to know where it really originated, and how it developed. He found a good deal of difference of opinion, even in Scandinavia, in regard to its being the best method, and it would be very interesting to know if it were still in use at Grängesberg.

In regard to the methods of electric ore finding, the statement was made that those methods had been developed and had proved successful in Sweden. Now, at one time great difficulties were experienced, inasmuch as several of the methods appeared to give very similar, if not identical, indications for an underground water channel and an underground vein of ore, and he was anxious to know how that difficulty had been overcome. He hoped, therefore, the author would give somewhat fuller details of the methods of electric ore finding which were being employed, and of the results that had been obtained.

Professor Dr. W. Petersson replied that shrinkage stoping mining was introduced at the Grängesberg Export Field in 1900, and at the Striberg mines in 1903, after the method had been studied in the United States of America by Swedish engineers. In both mines the method was still used, and it had later been introduced at several other iron mines where the conditions had been favourable. Magazine mining was tried in a part of the Åmmeberg mines, but proved unsatisfactory for that ore deposit; overhand stoping with filling had been reintroduced, a method which had been used in that mine since 1858.

The Swedish electrical prospecting methods were well known. A detailed description of them was given in an article "Electrical Prospecting in Sweden." in Year-Book 17 (1923), No. 8, of the Geological Survey of Sweden. Those methods worked with alternating current of such frequency that, in practice, ordinary subsoil water, swamp water, or lake water, gave no indications whatever. As an instance, it might be mentioned that a large ore-body in Vesterbotten was found under

a lake by prospecting on the ice, particulars of which discovery were to be found in the above-mentioned article. Although there were cases where the water was more dissociated, and consequently had a greater conductivity, than in the examples quoted in the Year-Book, yet there was generally no doubt as to whether an indication were caused by such conducting solutions or by ore-bodies, as the latter usually had a more limited extension than the former, and might thus be recognised by the form and kind of the indication, even when occurring in conjunction with solutions.

THE EFFECT OF NITROGEN ON CHROMIUM AND SOME IRON-CHROMIUM ALLOYS.*

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Abstract.

Some iron-chromium alloys prepared in a carbon-ring furnace were found to be contaminated with nitrogen. In view of the importance of this fact in connection with other work, an investigation was made into the conditions under which nitrogen is absorbed by iron, chromium, and iron-chromium alloys. The microstructures and hardness of alloys containing nitrogen were also studied.

Samples of pure iron, chromium, and iron-chromium alloys were treated with nitrogen for thirty to fifty minutes by passing the gas over the surface of the metals maintained in the liquid state in a high-frequency induction furnace. The microstructure and hardness of the alloys were observed and confirmed by reference to a series of less pure iron-chromium alloys containing nitrogen, made in the carbon-ring furnace.

Structures of the martensitic and pearlitic type similar to those found in carbon steels are produced in the pure iron-chromium alloys by the addition of nitrogen. The hardness of iron-chromium-nitrogen alloys (region 12 per cent. chromium) exhibiting the martensitic type of structure is modified on heat treatment.

Nitrogen is readily absorbed at high temperatures by iron-chromium alloys in the solid state, and the penetration of the material by nitrogen appears to be especially rapid in the vicinity of crystal grain boundaries.

The investigation described in the present paper forms Part IV. of a systematic research on the alloys of iron which is in progress at the National Physical Laboratory under the auspices of the Alloys of Iron Research Committee, and under the immediate direction of Walter Rosenhain, D.Sc., F.R.S.†

In the course of attempts to prepare pure iron-chromium

* Received July 16, 1926.

† For Parts I., II., III., see *Journal of the Iron and Steel Institute*, 1924, No. II. p. 85.

alloys, mixtures of iron and chromium containing appreciable amounts of nitrogen were unintentionally produced. Owing to the high temperatures essential to the melting and alloying of the constituent metals, the only suitable furnace then available was of the carbon-ring type,[1] and in spite of the refractory muffles surrounding the crucible and charge it was impossible completely to exclude oxygen, nitrogen, and carbon. Before it was realised how readily nitrogen is absorbed by the alloys it was customary to sweep out the muffle with a continuous stream of nitrogen in order to lessen the risk of contamination of the melts with oxygen and carbon. This procedure materially reduced the quantity of oxygen and possibly carbon in the alloys, but increased the nitrogen content. At a later date, when access was obtained to a high-frequency furnace in which complete control of the atmosphere in the melting chamber was possible, some further experiments were made in which the metals and alloys in the liquid state were deliberately treated with nitrogen. It has not yet been possible to make a thorough investigation of the iron-chromium-nitrogen system, but the ease of absorption of nitrogen, and the profound alteration in the alloys caused by the presence of a small percentage of this element, make it desirable to publish these observations.

The alloys and metals on which the results are based may be conveniently dealt with in three sections:

I. Four melts specially treated with nitrogen in the high-frequency induction furnace.
II. Series of chromium-iron alloys made in the carbon-ring furnace, in which a nitrogenous atmosphere was present.
III. Some alloys originally free from nitrogen, but which absorbed that element during heat treatment in the solid state.

I.—High-Frequency Induction Furnace Melts.

(*a*) *Pure Iron.*—Electrolytic iron of high purity was melted in a crucible of pure alumina, and a stream of nitrogen passed over the surface of the molten metal for thirty minutes. The pressure in the furnace was then reduced to 1 to 2 millimetres of mercury and the melt allowed to solidify.

Analysis revealed the presence of 0·02 per cent. nitrogen, a small but definite amount, since it was considered that 0·01 per cent. of nitrogen could be detected under the conditions of analysis. The metal presented a normal appearance under the usual microscopic examination.

In view of previous observations [2,3] it was not expected that pure iron, in the liquid state, would absorb a large quantity of nitrogen, but something in the nature of a check was thought desirable before studying the effect of nitrogen on chromium and the iron-chromium alloys.

(*b*) *Chromium.*—A sample of commercial chromium when in the liquid state was treated in a similar manner with nitrogen for fifty minutes. On attempting to produce a vacuum in the melting chamber of the furnace at the conclusion of the treatment, gas was evolved rapidly from the metal as soon as the pressure had been reduced below half an atmosphere. Accordingly the metal was allowed to solidify under about half an atmosphere pressure of gas.

The nitrogen content of the product was 3·9 per cent.; the Brinell hardness (2 millimetre ball; 40 kilos) was 315, while the figure for commercial chromium was 160 to 170. Under the microscope the polished and etched section of the metal showed the presence of a pale yellow constituent often arranged in dendritic formation. See Fig. 2 (Plate VIII.).

As the commercial chromium was not as pure as was desirable, a further experiment was made with electro-deposited chromium, in which the only impurities appeared to be hydrogen and possibly oxygen. On this occasion the metal was melted by means of the high-frequency induction furnace, in a crucible of pure alumina, the whole melting chamber being open to the air.

Although the metal was only maintained in the liquid state for a short time (one or two minutes) the percentage of nitrogen absorbed was found to be 2·38 per cent.

Microscopic examination revealed primary dendrites of metal together with a eutectic of the metal plus yellow constituent (possibly nitride). (See Figs. 3 and 4.) Hard particles of chromium oxide, which were plentiful in the metal, gave rise to the dark specks seen mainly in the white constituent of Fig. 3, and made polishing of the specimen difficult. Electro-deposited

chromium after melting under vacuum conditions presents the usual single-phase structure of a pure metal under the microscope, and no yellow constituent is visible.

An attempt to determine the melting point of chromium yielded some interesting results. Commercial chromium was melted in a carbon-ring furnace and then allowed to cool slowly. When the thermocouple sheath was introduced into the melt at a temperature of 1630° C., it was found impossible to push the sheath to the bottom of the crucible, as solidification had already commenced. A considerable arrest in the rate of cooling was also observed in the neighbourhood of 1580° C., this probably indicating the freezing of the coarse eutectic of metal and yellow constituent. On analysis, 2·1 per cent. of nitrogen was found in the material.

From these observations it will be seen that chromium in the liquid state readily absorbs nitrogen, and that the melting point of the pure metal cannot be ascertained when the melt is exposed to the atmosphere.

Presumably, commercial chromium absorbs a certain amount of nitrogen during manufacture, since in many samples examined microscopically a thin layer of faintly yellow constituent could be seen between the crystal grains (Fig. 5). On analysis, one sample gave 0·07 per cent. nitrogen.

(*c*) *Alloy of Iron and Chromium containing Nitrogen.*

Analysis.

	Per Cent.
Chromium	11·82
Nitrogen	0·12
Carbon	less than 0·02

This alloy was made up under vacuum conditions with electro-deposited iron and chromium, and then nitrogen was passed for thirty-five minutes over the surface of the liquid metal. The polished and etched section of the furnace-cooled ingot showed a martensitic structure under moderate powers (Fig. 6), but a few relatively large non-martensitic areas were also observed. Samples of this material held for fifteen minutes at 1394° C. and 1250° C. respectively, and then quenched, were entirely martensitic in character. As previous experience suggested that a transition point or narrow range was likely to be present in this material near 802° C., a specimen was held at 790° C. for two hours and

then quenched. The martensitic structure had disappeared, and under low magnification a microsection of the material rather resembled a pure metal or solid solution alloy (see Fig. 7). The speckled appearance of some grains under high power suggested, however, that some fine particles of a second constituent were present (see Fig. 8, Plate IX.). Heat treatment of the alloy was responsible for great changes in hardness, as will be seen below:

Brinell hardness tests (2-millimetre ball; 40 kilos)—

Alloy rapidly furnace-cooled	315
Alloy annealed for two hours at 900° C. and quenched	315
Alloy annealed for two hours at 790° C. and quenched	115

(*d*) *Alloy of Iron and Chromium containing Nitrogen.*

Analysis.

	Per Cent.
Chromium	24·6
Nitrogen	0·27
Carbon	less than 0·02

This material was also made up, under vacuum conditions, from electro-deposited iron and chromium, and a stream of nitrogen passed over the surface of the molten metal for thirty minutes. The microsection of the furnace-cooled alloy indicates the presence of large crystal grains in which elongated bodies of a second constituent have separated.

In the vicinity of the original grain boundaries many of the "islands" had developed a fine lamellar or pearlitic structure (Fig. 9). When the alloy was quenched from 1358° C., the appearance of the microsection suggested that the separation of the second constituent in large masses was practically suppressed. On the other hand, the material held for fifteen minutes at 1220° C., and then quenched showed masses of the second constituent which had evidently undergone a "balling up" process (see Fig. 10). Finally it was found that all the "islands" of the second constituent had developed the fine lamellar structure when the alloy was annealed for two hours at 790° C. and quenched. The "background" or material surrounding the "islands" of the second constituent sometimes presented a speckled appearance after etching, but, partly owing to the extreme difficulty of etching the annealed material, it was impossible to determine whether or not this was due to a separation of fine particles. It was noted that the martensitic type of structure was absent from this

alloy, and that no considerable changes of hardness took place as the result of heat treatment.

Brinell hardness tests (2-millimetre ball; 40 kilos)—

Alloy rapidly furnace-cooled	165
Alloy annealed for two hours at 900° C. and quenched . .	178
Alloy annealed for two hours at 790° C. and quenched . .	192

II.—Series of Chromium-Iron Alloys made up in Carbon-Ring Type Furnace in which a Nitrogenous Atmosphere was Present.

Table I.—*Analyses of Series of Chromium-Iron Alloys.*

Alloy No.	Chromium.	Nitrogen.	Carbon.
	Per Cent.	Per Cent.	Per Cent.
1	0·21	0·06	0·018
2	0·58	0·03	0·03
3	0·96	N.D.	0·024
4	1·38	N.D.	0·03
5	3·0	0·008	0·03
6	4·25	N.D.	0·044
7	5·12	0·013	0·044
8	6·6	0·014	0·036
9	7·7	0·07	0·062
10	12·6	N.D.	0·05
11	17·44	0·053	0·054
12	24·0	N.D.	0·046
13	27·4	0·25	0·02
14	34·4	0·23	0·026
15	39·6	N.D.	0·03
16	43·6	0·14	0·038
17	54·0	1·83	0·042
18	58·5	N.D.	0·098

N.D. = not determined.

In all cases electrolytically deposited iron and commercial chromium were used in the preparation of the alloys. Since the chromium contained 0·03 per cent. carbon, and the iron 0·005 to 0·01 per cent., it would appear that a certain amount of carbon was absorbed by the alloys during melting. In alloys containing under (say) 20 per cent. chromium the nitrogen and carbon were usually present in comparable quantities, but with higher percentages of chromium the amount of nitrogen increased rapidly. Thus, a 54 per cent. chromium alloy contained 1·83 per cent. of nitrogen, while the carbon was recorded as 0·042 per cent.

Although the amount of nitrogen did not increase uniformly with the amount of chromium in the alloys, yet it was possible to trace a regular change in the microstructure and hardness of the alloys from 0 to 60 per cent. chromium. Structures were obtained in every way similar to those presented by the two pure alloys which have been specially treated with nitrogen (see above). Fig. 11 shows a microsection of a 17·44 per cent. chromium alloy which had been quenched from 1250° C.; but in this case the martensitic appearance is confined to large "islands" which separated just above the quenching temperature.

Perhaps the 39·6 per cent. alloy yielded the most typical microstructures. When quenched from 1400° C. the alloy consisted of large polygonal grains, but a partially arrested transformation had apparently given rise to the fine markings which will be seen in Fig. 12.

A microsection of the material quenched from 1200° C., however, shows that "islands" of a second constituent have separated, and that some of these islands have developed a lamellar structure (Fig. 13). This lamellar or pearlitic structure is visible in all the islands when the alloy has been quenched from 1170° C. (Fig. 14, Plate X.).

In the 54 per cent. chromium alloy (nitrogen, 1·83 per cent.) the transformations took place in a modified way and at higher temperatures. Thus, in material quenched at 1400° C. the "islands" of second constituent had already separated, and many of them presented a sorbitic rather than a pearlitic appearance. The matrix had also developed a criss-cross structure, but on a much larger scale than in the 39·6 per cent. chromium alloy mentioned above (see Fig. 15).

Figs. 16 and 17 represent microsections of the alloy (54 per cent. chromium) quenched at 1310° C. and 1173° C. respectively. It will be observed that the "islands" ultimately all develop a coarse lamellar structure, while the criss-cross markings in the matrix become finer and finally disappear as the quenching temperature is lowered.

Hardness.—As will be seen from Fig. 1, the hardness of the furnace-cooled alloys varies in a consistent manner with the chromium content. The hump in the hardness curve reaches its maximum altitude in the vicinity of 12 per cent. chromium

and is associated entirely with a martensitic type of structure in the material (see Fig. 6). These alloys were to a large extent "self-hardening," and could only be obtained in the soft state by deliberate slow cooling or annealing.

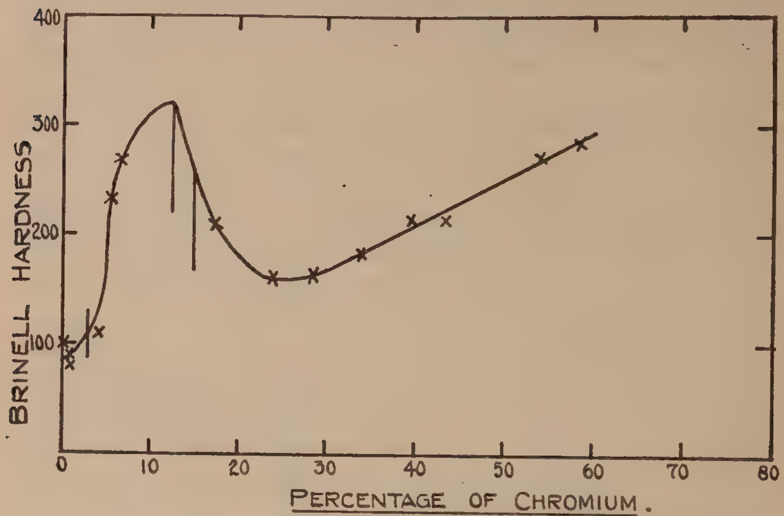

Fig. 1.—Brinell Hardness Values of Furnace-Cooled Iron-Chromium Alloys.

Lengths of vertical lines indicate the range of hardness of some alloys which apparently were incompletely hardened under the conditions of cooling.

III.—Absorption of Nitrogen by Alloys in the Solid State.

Chromium-iron alloys ranging in composition from 0 to 30 per cent. chromium were found to absorb nitrogen if annealed at moderate or high temperatures under conditions which permitted access of nitrogen.

Some chromium-iron alloys were annealed for $6\frac{1}{2}$ hours at 1350° C. in argon, but small amounts of nitrogen evidently entered the annealing chamber either through small leaks or as an impurity in the argon. The nitrogen absorbed under these conditions was readily detected by chemical and microscopic analysis.

Chemical analyses for two typical alloys are given in Table II.

FIG. 2.—×200.

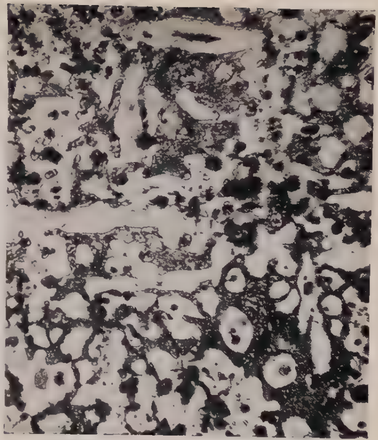

FIG. 3.—×100.

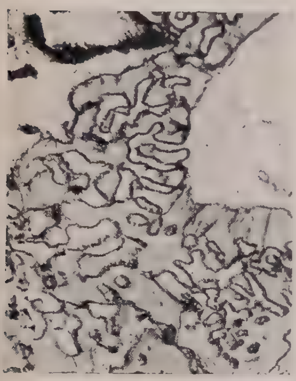

FIG 4.—×800.

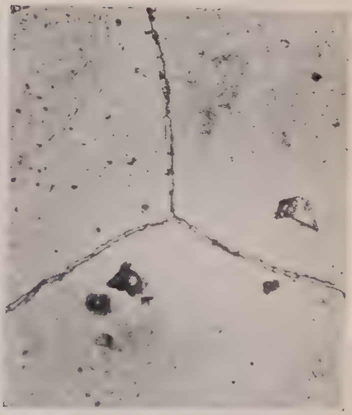

FIG. 5.—×150.

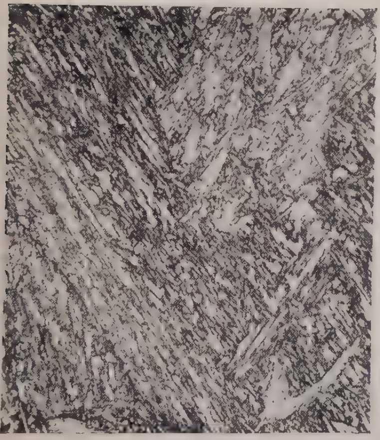

FIG. 6.—×400.

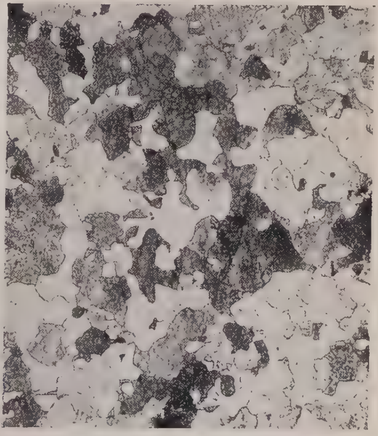

FIG. 7.—×250.

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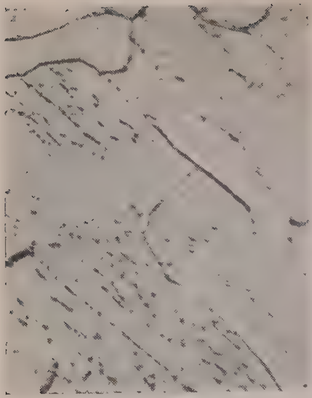

FIG. 8.—×2000.

FIG. 9.—×2500.

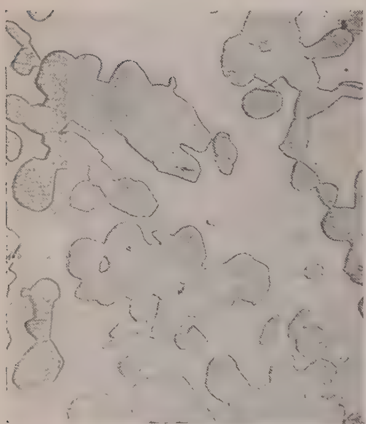

FIG. 10.—×200.

FIG. 11.—×300.

FIG. 12.—×300.

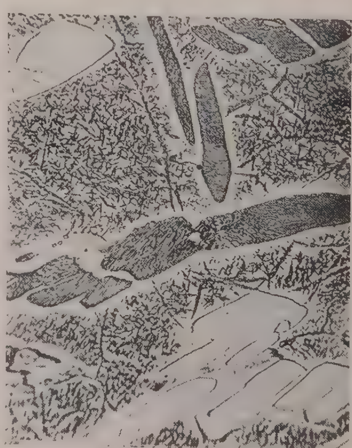

FIG. 13.—×300.

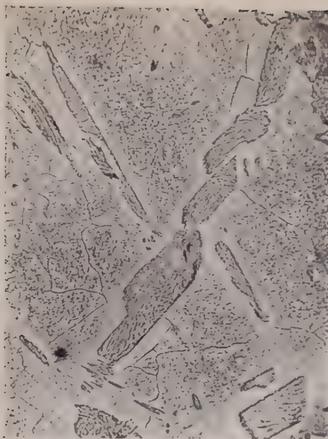

FIG. 14.—×300.

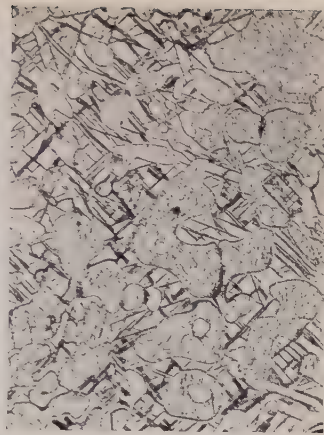

FIG. 15.—×300.

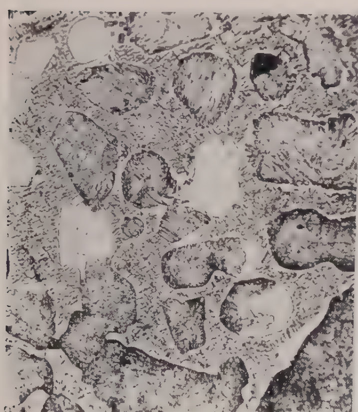

FIG. 16.—×300.

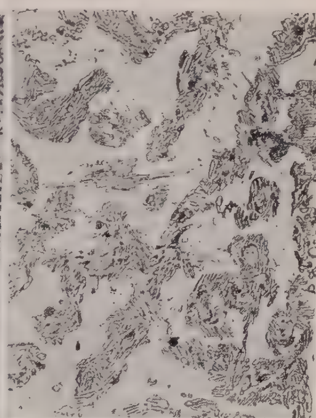

FIG. 17.—×300.

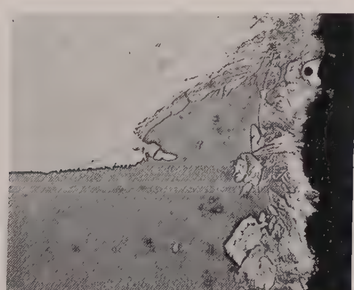

FIG. 18.—×200.

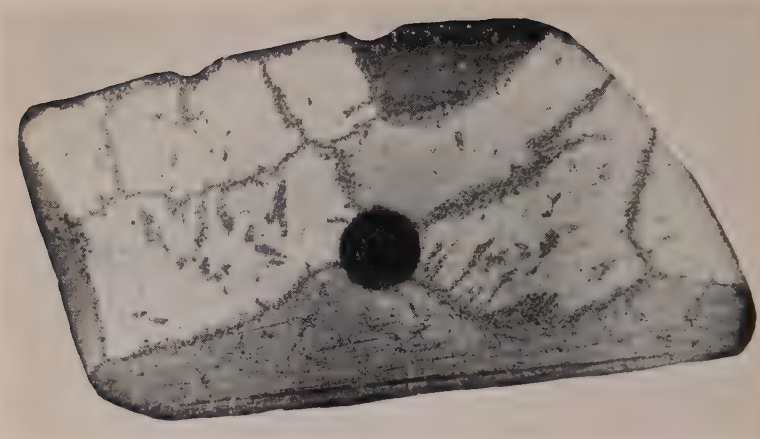

FIG 19.—×6.

FIG. 20.—×750.

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TABLE II.

Alloy No.	Chromium Content.	Nitrogen Content before Annealing.	Nitrogen Content after Annealing.
	Per Cent.	Per Cent.	Per Cent.
1	19·0	0·015	0·035
2	24·6	0·02	0·04

Heating the samples to 1000° C. for thirty minutes under an air pressure of a few millimetres not only leads to the usual oxide coating on the surface, but also to an appreciable absorption of nitrogen. Fig. 18, which represents the edge of a polished sample of 10·4 per cent. chromium alloy heated under these conditions, shows how the nitrogenous constituent has diffused inwards from the surface of the specimen, and that a specially rapid advance has occurred along a crystal boundary.

The microsections of a sample of iron-chromium alloy (10·7 per cent. chromium) which had been heated to 1000° C. in air at ordinary pressure, indicates that nitrogen has found its way to the centre of the specimen, chiefly by way of the crystal boundaries (Fig. 19, Plate XI.). (The dark circular patch near the centre of the specimen represents a hole drilled for the purpose of thermal analysis.)

CONCLUSIONS.

Nitrogen is rapidly absorbed by chromium in the liquid state, and alloys containing up to 3·9 per cent. nitrogen are readily obtained.

When nitrogen is passed for a considerable time over the surface of molten iron, only a small amount of nitrogen is retained (0·02 per cent.).

Alloys of iron and chromium, both in the liquid and solid states, take up nitrogen at high temperatures, and in general the quantity of nitrogen in the alloys increases with the chromium content.

In alloys of composition near 12 per cent. chromium, nitrogen gives rise under proper conditions to a martensitic type of structure closely resembling that usually associated with iron-carbon alloys. The hardness of these alloys can be considerably

modified by heat treatment, and ranges from about 115 Brinell in the annealed state to 315 Brinell when quenched above the critical range.

Most of the alloys containing nitrogen in the range 20 to 60 per cent. chromium present a two-phase structure under the microscope, except in some cases where the material has been quenched at a temperature immediately below the melting point. Although one of these constituents invariably develops a structure of the sorbitic or pearlitic type on suitable heat treatment, these changes are not accompanied by any great variation in hardness. This pearlitic or lamellar type of structure which characterises the alloys with 20 to 30 per cent. chromium containing nitrogen is known to be absent from the corresponding pure iron-chromium alloys. Further, the deliberate addition of 0·05 per cent. carbon to a 28 per cent. (approx.) chromium alloy free from nitrogen fails to produce any signs of a lamellar structure in the furnace-cooled material, although a considerable amount of a second constituent is visible (Fig. 20).

It would appear from this investigation that the presence of nitrogen in iron-chromium alloys can give rise to structures closely resembling those generally attributed to carbon in ordinary steel, and, further, that at high temperatures the pure alloys of iron and chromium, whether solid or liquid, readily absorb nitrogen from the atmosphere.

The author is indebted to Mr. P. G. Ward, B.Sc., A.R.C.S., for estimating the nitrogen content of the samples; to Mr. T. E. Rooney, A.I.C., A.M.S.T., and members of the staff for other analyses; and to Mr. A. J. Cook for general assistance during the investigation.

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"Nitrogen Process of Surface Hardening," *The Metallurgist*, April 30, 1926, p. 60.

References to the effects of nitrogen in steel and to nitrogen case-hardening processes will be found in the Abstract Section of the *Journal of the Iron and Steel Institute*.

ANOMALIES IN HEAT CONDUCTION AS INVESTIGATED IN SPHERICAL STEEL SPECIMENS, WITH SOME DETERMINATIONS OF THERMAL (AND ELECTRICAL) CONDUCTIVITY IN IRON AND CARBON STEELS.*

By C. BENEDICKS, H. BÄCKSTRÖM, and P. SEDERHOLM
(Metallografiska Institutet, Stockholm).

PART I.—ANOMALIES IN HEAT CONDUCTION OF SPHERICAL STEEL SPECIMENS.

By C. BENEDICKS and P. SEDERHOLM.

Introduction.

On account of a request from the industrial side, the Metallografiska Institut made some determinations of the heat conductivity of two steel specimens. A high degree of reliability being desired, and in view of the difficulties met with in the ordinary methods of eliminating external heat transfer, it was decided to adopt a spherical method, which in itself is necessarily free from that source of error. At the same time it was considered desirable to verify definitely some results obtained earlier on cylindrical specimens.

In the subsequent work, however, very considerable difficulties were encountered; enormous local variations in the temperature differences measured were observed. Though successive improvements were made in the procedure, so that in its final form it might be described as a precision method, these variations were still found to persist. Besides its scientific interest, the knowledge of these variations is considered to be of a practical interest, and hence a short description will be given.

Theory of the Spherical Method.

The use of a hollow homogeneous sphere, heated centrally, the temperature gradient of which is ascertained, is the best method for eliminating errors due to external heat transport. As a matter of fact, it was used by Nusselt [1] for substances of low conductivity, but it does not seem to have been used previously for metallic conductors.

* Received June 8, 1926.

The theory is simple, on the supposition that under conditions of equilibrium the heat flows throughout in a radial direction. The heat quantity dQ which flows in one second through a section, distant r from the centre, of an infinitely small solid angle $d\omega$, is expressed, according to the fundamental formula of heat conduction, by the equation

$$dQ = -\frac{\lambda d\theta \times d\omega \times r^2}{dr},$$

where θ = the temperature and λ = the thermal conductivity.

Writing instead $$\frac{dQ}{d\omega} \times \frac{dr}{r^2} = -\lambda d\theta,$$

and observing that, on account of the assumed symmetry,

$$\frac{dQ}{d\omega} = \frac{Q}{4\pi}$$

(Q = total heat generated per sec.), the following expression is obtained:

$$-\int_{r_1}^{r_2} \frac{dr}{r^2} = \frac{4\pi\lambda}{Q} \int_{\theta_1}^{\theta_2} d\theta$$

After integrating, the final formula is obtained:

$$\lambda = \frac{(r_2 - r_1)}{4\pi r_1 r_2} \times \frac{Q}{\theta_1 - \theta_2}$$

Thus, knowing the heating effect Q from the intensity of current i and the voltage V used:

$$Q = 0{\cdot}239\ iV \text{ cal./sec.},$$

it is only necessary to determine the temperature difference between the two points, situated at the distances r_1 and r_2 respectively.

Experimental Arrangement.

The steel specimens had the following composition:

Table I.

Mark.	Carbon per Cent.	Silicon per Cent.	Manganese per Cent.	Phosphorus per Cent.	Sulphur per Cent.
A . .	0·50	0·24	0·32	...	...
B . .	0·71	0·24	0·18	...	...
C . .	0·24	0·13	0·49	0·030	0·027

They were taken from thick tubes, and their size permitted the shaping of hemispheres, as large as 45·0 millimetres in outside diameter. The exact spherical shape was obtained by using the rotating tool-rest of a Seneca Falls Mfg. Co. lathe, after having carefully set its axis of rotation to intersect the axis of the lathe. The inner spherical space was turned out to a diameter of 11·5 millimetres.

In order to hold the thermocouples exactly in position, circular grooves $\alpha_1\alpha_2$ (Fig. 1) were cut. The junctions of the thermo-

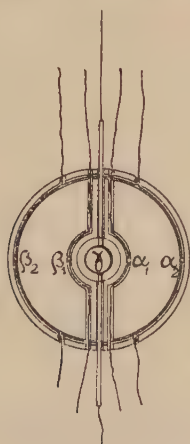

FIG. 1.

couples (copper-constantan, 0·2 millimetre) formed small spheres, and were placed at α_1 and α_2; another pair were similarly placed at β_1 and β_2 for the sake of control. To lead out the wires, the grooves were continued as shown in the figure. An improved method of arranging the thermocouples will be described later; a photograph of the sphere is shown in Fig. 9 (Plate XII.), where its mounting on three wooden pegs and other details are to be seen.

As heater (γ, Fig. 1) a number of different coils of constantan wire were first used, being wound in different ways, and partly surrounded by a spherical copper shell, which was separated from the steel by a layer of paper. Subsequently, in order to avoid any eccentricity, a very regularly shaped heating coil was made by

winding a 0·1 millimetre nichrome wire (beginning at each pole) on a 5·0 millimetre steatite ball, which was mounted on a thin steel capillary (0·7 millimetre outside diameter, and insulated by silica capillaries). This coil, the resistance of which was 114 ohms, could be adjusted very symmetrically by means of the capillary. A straight central groove was provided for the leads of the heating element.

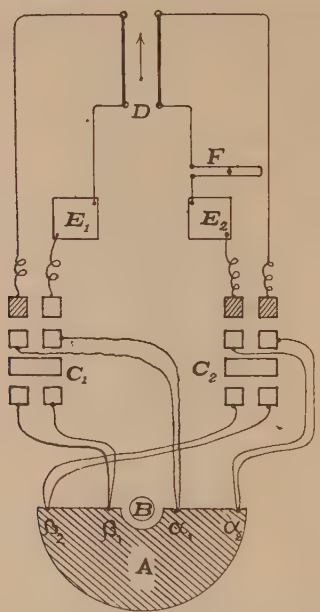

FIG. 2.

The upper half of the sphere was pressed against the lower by a clamping device (shown dismantled in Fig. 9).

The experimental arrangement as first used is represented diagrammatically in Fig. 2. The essential parts are the specimen A with its thermocouples, and the heating sphere B, the effect of which was read on precision instruments not drawn in the figure. By means of two precision switches C_1, C_2 (copper blocks in good thermal contact), the thermocouples $\alpha_1\alpha_2$, or $\beta_1\beta_2$, were connected with the two circuits of the differential galvanometer D, containing also equal resistances E_1, E_2, and a small resistance F of copper used for balancing the two circuits.

The galvanometer first used (Siemens and Halske) had a fairly constant zero; 1 millimetre displacement of the spot of light at a distance of 1 metre corresponded to $1 \cdot 40 \times 10^{-7}$ volt for each winding.

Preliminary Results.

In spite of the strict symmetry of the apparatus, very variable results were obtained from the thermocouples $\alpha_1\alpha_2$ and $\beta_1\beta_2$; these, of course, were used for the sake of control, and ought to have given identical results.

As an example, the figures shown in Table II. may be given. The temperature differences are calculated by means of the formula $\theta_1 - \theta_2 = 0 \cdot 0252u$ found by calibration, where u = deflection of the differential galvanometer.

Table II.

Steel.	i. Amp.	V. Volt.	Q. Cal./Sec.	u_α. Millimetres.	u_β. Millimetres.	$\theta_{\alpha_1} - \theta_{\alpha_2}$. Degree Cent.	$\theta_{\beta_1} - \theta_{\beta_2}$. Degree Cent.	(Average) $\theta_1 - \theta_2$. Degree Cent.	(Apparent) λ.
A	0·2000	10·59	0·506	17·0	45·8	0·428	1·154	0·791	0·0460
	0·2192	9·72	0·508	26·3	38·9	0·663	0·980	0·821	0·0445
	$r_1 = 6 \cdot 91$ mm.; $r_2 = 18 \cdot 38$ mm.; $r_2 - r_1 = 11 \cdot 47$ mm.								
B	0·1990	10·58	0·503	20·7	53·2	0·522	1·341	0·931	0·0385
	0·2186	9·70	0·507	16·0	50·3	0·403	1·267	0·835	0·0432
	$r_1 = 7 \cdot 32$ mm.; $r_2 = 21 \cdot 13$ mm.; $r_2 - r_1 = 13 \cdot 81$ mm.								

As seen by these figures (obtained with two different heating coils respectively), the temperature difference in the same specimen was subject to enormous variations. There was evidently not much object in taking the average temperature difference; this was done, however, the heat conductivity values given in the last column being obtained. The averages of those apparent values for λ were: for A 0·047, for B 0·042, which might possibly indicate a slightly lower conductivity in B than in A.

Final Experimental Arrangement.

Everything in the above-described apparatus was examined for any source of error, but without success.

In order to arrive at quite decisive results, after much laborious work, the following method was adopted, which is quite independent of any resistance changes in the different thermocouples or galvanometer circuits, and permits of an accurate checking of the thermocouples at any moment.

In the first place, a very precise means was adopted in order to

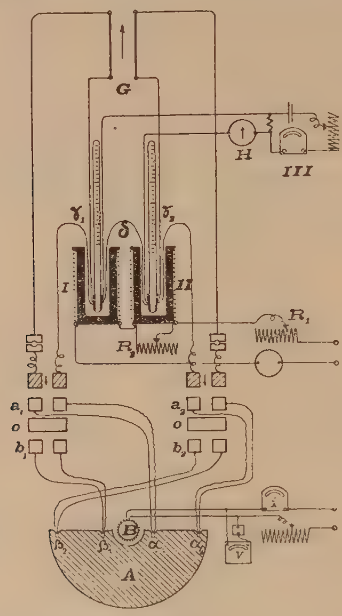

Fig. 3.

obtain reliable temperature indications from the thermocouples. Each of the four constantan and the four copper wires were soldered into a 1 × 1 millimetre silver cylinder, previously perforated with a fine hole. After having made the grooves for the wires in one of the hemispheres, holes about 1·05 millimetre in diameter and 1·5 millimetre deep were drilled into them, close together, and into these holes the small cylinders were driven by means of a suitable punch. In this way the contact and the geometrical definition obtained were very satisfactory.

The method of determination was based entirely on the use of compensation. As illustrated by Fig. 3, each thermocouple,

say α_1 and α_2, was simultaneously compensated against two further identical thermocouples γ_1, γ_2, the junctions of which were placed in electrically heated, thick copper tubes I. and II., respectively. Each of these contained a precision mercury thermometer (0° to 100° C., reading to $\frac{1}{10}$°), one of which had been calibrated at the Reichsanstalt. The thermo-elements γ_1 and γ_2 were soldered into copper wrappers closely surrounding the mercury bulbs. Electrically insulated, but in close thermal contact with them, a series of six successive iron-constantan thermocouples δ (drawn as a single one in Fig. 3) also surrounded the thermometers closely, the whole being placed in paraffin oil. The electromotive force of these thermocouples was measured by the compensation arrangement shown at III. The mercury thermometers served as indicators, and they also at any time permitted of an easy calibration of the thermocouples.

In principle, the temperature of I. had to be adjusted by means of the resistance R_1 so as to coincide with that of α_1 or β_1, and also the temperature difference of I. and II., by means of the shunt resistance R_2, so as to coincide with the temperature difference $\alpha_1\alpha_2$, or $\beta_1\beta_2$. In practice, however, it was not necessary to have the first adjustment made very carefully, as it had a very slight influence on the difference values.

The moving-coil galvanometer was replaced by a more sensitive, and much more rapidly moving magnetic needle microgalvanometer (C. Benedicks), the zero of which was still more constant (G, Fig. 3). A moving-coil galvanometer H was used for the compensation of the thermocouples.

Procedure of a Determination.

A steady temperature having been established in the sphere (after two or three hours), the determination of the temperature differences was done in the following way. Having adjusted the temperature T_1 in I. so as to differ only slightly from the temperature θ_1 (in α_1), readings were taken of the effect produced in the specimen and of the following items: electromotive force E of the differential elements δ; at a moment when exact compensation was obtained at H, another observer read the deflections a_1a_2, and b_1b_2, of the differential galvanometer G; these deflections

corresponded to the momentary difference between $T_1 - T_2$ on the one side, and $\theta_{\alpha 1} - \theta_{\alpha 2}$, or $\theta_{\beta 1} - \theta_{\beta 2}$, on the other.

The temperatures T_1 and T_2 were then read directly with a telescope, and finally, merely for control, the deflection a_1 corresponding to the temperature difference $T_1 - \theta_{\alpha 1}$, and the zero of G.

In order to illustrate the method, the following example of an experiment is given (Table III.).

TABLE III.—*Series* 13. *Steel B.*

Date, April 30, 1926.

Time. Hr. Min.	i. Amp.	V. Volt.	E 10^{-5} Volt.	Zero of G. Millimetres.	a_1a_2. Millimetres.	b_1b_2. Millimetres.	a_1. Millimetres.	T_1. ° C.	T_2. ° C.	$T_1 - T_2$. ° C.
A.M.										
11.10	0·1400	16·00	...	...	...	...	...	...	...	...
P.M.										
2.20	0·1396	15·99	− 159·0	251·0	223·0	242·0	166	56·60	56·19	+ 0·41
26	...	...	− 172·0	251·0	219·0	240·0	162	56·76	56·40	+ 0·36
30	...	...	− 168·0	251·5	221·0	241·0	161	56·95	56·51	+ 0·44
42	...	...	− 127·9	251·5	228·0	249·0	179	56·99	56·68	+ 0·31
46	...	...	− 125·8	251·5	229·0	249·5	182	57·01	56·70	+ 0·31
50	0·1398	15·98	− 112·4	251·7	231·4	253·0	187	57·01	56·72	+ 0·29
55	...	...	− 99·5	251·5	234·5	255·0	193	57·01	56·79	+ 0·22
58	...	...	− 84·6	251·3	236·5	257·3	194	57·05	56·86	+ 0·19
3.2	...	...	− 73·0	251·0	239·4	260·3	196	57·11	56·98	+ 0·13
7	...	...	− 44·9	251·4	246·8	267·0	195	57·20	57·12	+ 0·08
9	0·1396	15·98	− 24·9	...	249·0	271·0	...	57·19	57·17	+ 0·02
12	...	...	− 15·2	251·3	251·2	272·5	200	57·19	57·20	− 0·01
15	...	...	− 8·6	...	253·0	274·0	...	57·28	57·30	− 0·02
18	...	...	...	...	258·0	278·0	195	57·30	57·40	− 0·10
20	...	...	+ 34·7	251·5	261·5	282·5	191	57·35	57·50	− 0·15
	0·1397	15·98		251·3						

By plotting these observations, with E as abscissæ and with a_1a_2 and b_1b_2 as well as $T_1 - T_2$ as ordinates, a diagram is obtained (Fig. 4) which is used for the evaluation of the temperature differences $\theta_1 - \theta_2$ in the specimen, in the following way. The straight line drawn through the observations a_1a_2 intersects the galvanometer zero line (xx', at 251·3 millimetres) at a point x. Consequently, for the corresponding value of E, or E_x, the following equation must hold:

$$\theta_{\alpha 1} - \theta_{\alpha 2} = \mathrm{T}_{01} - \mathrm{T}_{02},$$

where T_{01} and T_{02} signify the true temperatures in I. and II. In order to evaluate $T_{01} - T_{02}$, we have only to draw through the origin of the $T_1 - T_2$, E co-ordinates (point p) a straight line pp' parallel to the straight line qq' given by the observations $(T_1 - T_2)$. It is to be noted that the vertical distance pq gives the exact measure of the zero difference ($-0{\cdot}05°$ C.) of the two thermometers, under the prevailing conditions; a direct comparison made at $+20°$ gave $-0{\cdot}09°$ C.

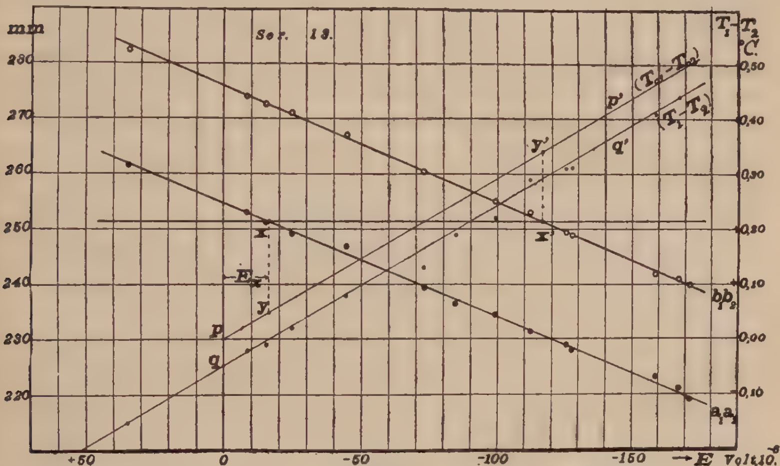

FIG. 4.

The point of intersection y of pp' and the vertical xy gives the true temperature difference; in this case

$$\theta_{a_1} - \theta_{a_2} = 0{\cdot}047° \text{ C.}$$

In the same way the analogous points x' and y' give the value

$$\theta_{\beta_1} - \theta_{\beta_2} = 0{\cdot}339° \text{ C.}$$

To judge from the extremely good constancy of the zero line, these values should be accurate to within a few units of the last decimal place. This, however, is scarcely the case: the galvanometer zero was read with open circuits, uninfluenced by any thermo-electric forces which might possibly exert some influence during the a_1a_2 and b_1b_2 readings. It was found that this uncertainty in the true zero position might amount to a few millimetres. But even if the absolute values obtained are still slightly

uncertain, this *in no way affects their difference*, which is here the salient point.

Some Controlling Experiments.

The result as obtained in the preceding paragraph may be affected by possible differences in the thermocouples. Hence, it is very convenient that the above method permits easy checking of the equality of the thermocouples. It is actually only necessary to slowly heat the vessels I. and II. (Fig. 3) while the specimen A is kept at a constant, strictly uniform temperature, and then to read the temperature difference $T_1 - T_2$ successively at deflections a_1a_2 and b_1b_2. By plotting these readings as a function of time, they were both found to fall strictly on the same curve, thus clearly proving the equality of the thermocouples. Only in one case (new wires being taken for the different spheres) was a difference obtained, but this amounted to only half a millimetre.

The central position of the heating coil was duly checked: on turning the coil finally used through 90°, practically no effect was discernible.

The rotation of the upper hemisphere proved to have no sensible influence, nor did a different pressure. Similarly, the outside conditions of the sphere (free on its holder or surrounded by different screens, cotton-wool, &c.) were found to have very little influence.

Consequently, no other possibility was left than that the enormous differences observed corresponded to the reality.

Final Results.

The final measurements, made as described above, gave the following results (Table IV.):

Table IV.

Steel.	r_1. Milli-metres.	r_2. Milli-metres.	$r_2 - r_1$. Milli-metres.	Q. Calories per Second.	$\theta_{\alpha_1} - \theta_{\alpha_2}$. Degrees Cent.	$\theta_{\beta_1} - \theta_{\beta_2}$. Degrees Cent.	Ratio. α/β.
A	7·48	20·22	12·73	0·472	0·181	0·070	2·6 : 1
,,	,,	,,	,,	1·008	0·388	0·114	3·4 : 1
B	7·67	20·40	12·73	0·475	0·047	0·339	1 : 7·2
,,	,,	,,	,,	1·010	0·065	0·554	1 : 8·5
C	8·31	20·43	12·12	0·527	0·160	0·098	1·6 : 1
,,	,,	,,	,,	1·058	0·120	0·055	2·2 : 1

It will be seen that, in spite of the very great care taken, the two temperature differences in the same specimens—which are supposed to be equal—are subject to enormous variations, amounting for B to so high a ratio as $1:8 \cdot 5$.

As these irregularities, which were proved later to be inherent to the metal, might be supposed to be quite exceptional, spheres were also made from a sample of a 50-millimetre "axle steel" (of composition already given as C in Table I.) and tested with the same precision. The plane of the hemisphere was here perpendicular to the axis. There was no reason to expect any special irregularity in this steel in view of its simple manner of production.

As will be seen from Table IV., the irregularity in this case (C) is actually somewhat less, but the ratio still amounts to a maximum of $2 \cdot 2 : 1$. The capricious character of the phenomenon, however, in this case is very conspicuous from the fact that a *lower* difference was found at the higher temperature.

On account of these irregularities, it would evidently be entirely illusory to attempt any calculation of λ from these figures.

Thermoscopic Observations.

The paradoxical results obtained rendered it desirable to study the thermal conductivity variations in other ways also. In the first place, a thermoscopic method was used. The end of a brass rod was turned spherical, with the same diameter as the inner cavity (diameter $11 \cdot 5$ millimetres). The surface of one hemisphere was coated with mercury copper iodide ($HgCu_2I_4$), which is known to possess a sharp transformation at 71° C., when the red colour changes into black. It was then warmed from the centre by means of the brass rod, which was evenly heated by a flame; in order to secure a uniform heat transfer the specimen was continuously rotated.

A considerable lack of symmetry of the heat conduction was evidenced in this way, the boundary between red and black differing very much from a regular circle.

Slightly conical cylinders (upper diameter, 48 millimetres; height, 24 millimetres) were then turned from the steels A and B; the upper plane surface was finely ground, and provided with a

small conical hole. A copper rod, which could be heated electrically, was fitted into this very accurately. This plane surface was coated with a thin layer of bees-wax, and allowed to cool. On heating the copper rod the resulting melting curve was observed (de Senarmont's method); it was likewise found, with this better method of heating, to be rather irregular. No actual measurements were, however, made.

Thermal Conductivity in Different Directions.

In order to obtain more accurate data, the following procedure was adopted.

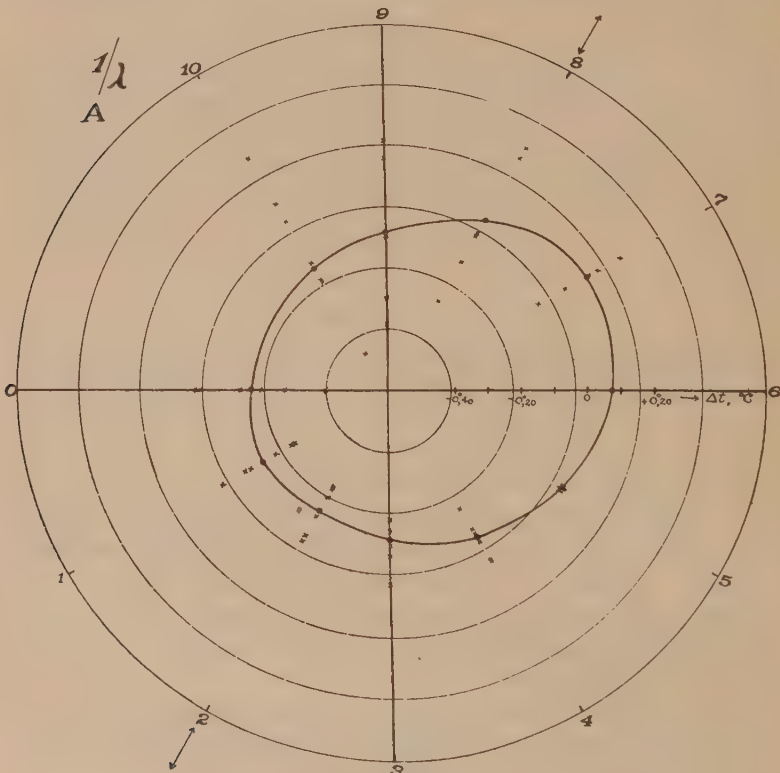

Fig. 5.

Each of the two junctions of a copper-constantan-copper element was soldered into a small silver disc (diameter, 2 milli-

metres). One of these was placed near the periphery on the smooth surface of the cylinders mentioned above, and was adjustable in a radial direction, while the other was pressed against the surface by a fibre disc, being movable around some 340° of a circle at a distance of 3 millimetres from the periphery. The

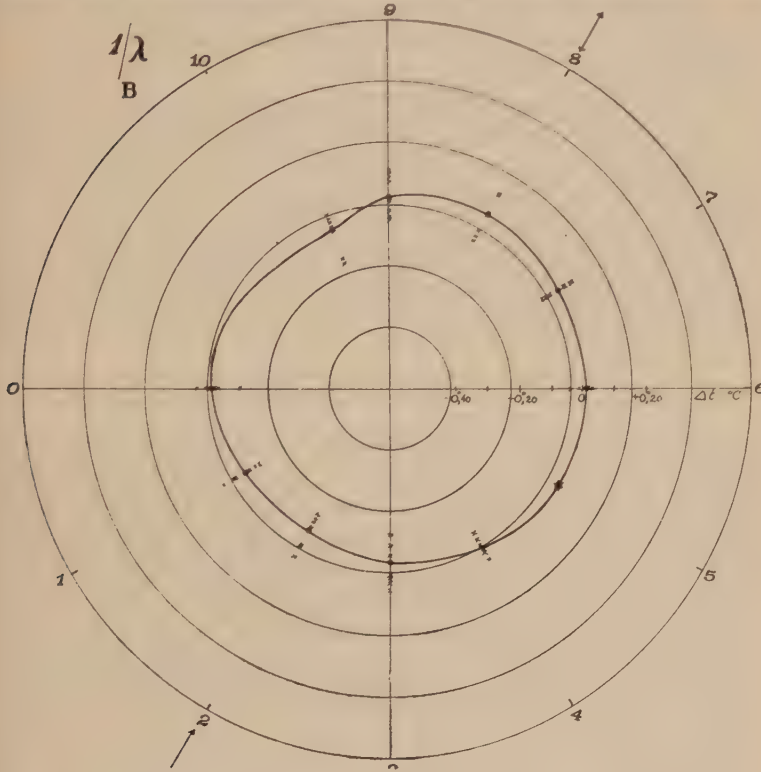

FIG. 6.

steel specimen was heated by the copper rod, fitting conically in its centre, and when a steady condition of temperature was reached, the first junction was adjusted so as to give only a very small deflection of a galvanometer connected to the thermocouple. The deflections were then read, the movable junction being placed successively at different angles.

The result is reproduced graphically in Fig. 5 for steel A, and in Fig. 6 for steel B. The curves are drawn through the mean

values of some different series obtained with a somewhat varying heating effect. It will be seen that for *A* very considerable variations in the temperature occurred, which were of the same order of magnitude as those more accurately determined previously. It must be purely a matter of chance how much the two temperature differences measured on the same diameter on both sides of the centre will differ; a maximum difference of about 0·25° C. is indicated by the curve.

For the specimen of steel *B* the temperature distribution was not quite so irregular; from Table IV. a still higher asymmetry would be expected here. The specimens being different ones, such individual variations seem quite natural.

Thus, these determinations have given additional evidence of the fact that *unexpectedly large temperature differences occur in the metals investigated*—even when the heating is operated in a strictly central way.

Electrical Conductivity in Different Directions.

It was next decided to investigate the electrical conductivity in the specimens. This was effected by using a method previously described by A. Gallander, for which a special bridge was constructed by C. Benedicks, and investigated by Herlin [(2)] and Esmarch.[(3)] By that means the electrical resistivity may be determined in any specimen possessing a plane surface. The resistance was measured in a radial direction, as well as at right angles to the radii, on a circle of about 13 millimetres radius. The results are recorded graphically in Fig. 7 for steel *A*, and in Fig. 8 for steel *B*.

As evidenced by Fig. 8, for steel *B* there is practically no difference between the electrical resistivity parallel or perpendicular to the radii; in steel A (Fig. 7) some difference is to be observed, but this may be due to the fact that the centre distance on which the measurements were made, was not identical in both cases. It may be concluded that the variations observed were not of a vectorial character, but must have been due to some heterogeneity of the metal. In any case, actual variations of the electrical resistivity are evidenced by these measurements,*

* We owe these to a great extent to the collaboration of Mr. T. Negresco, Civil Engineer.

and they are apparently analogous to those of the thermal resistance.

There is, however, a very considerable difference, inasmuch as the variations in electrical resistivity do not exceed 5 per cent.,

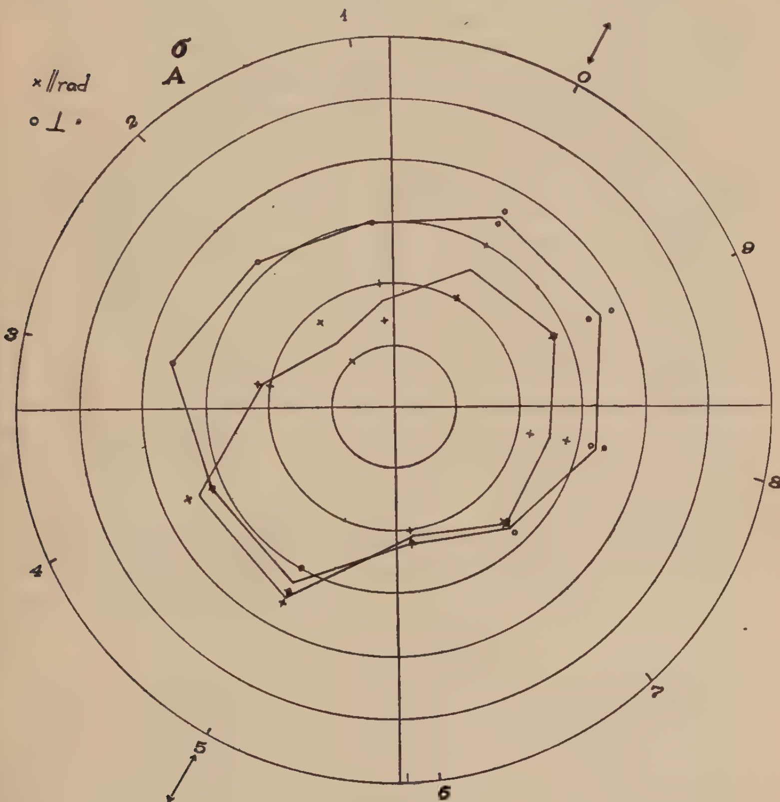

FIG. 7.

while the variations in thermal resistivity—on the assumption that they may be estimated from the variations in temperature—are enormous.

The electrical resistivity of two cylinders 200 millimetres in length and 8 millimetres in diameter was also determined, using the Thomson bridge. The results are given in Table V., together with the values calculated from Benedicks' formula,[(4)] in which the

assumption is made that the influence of the carbon content for *A* corresponds with about 0·2, and for *B* with 0·27 per cent. dissolved carbon, which is found, at least in many cases, to hold true.

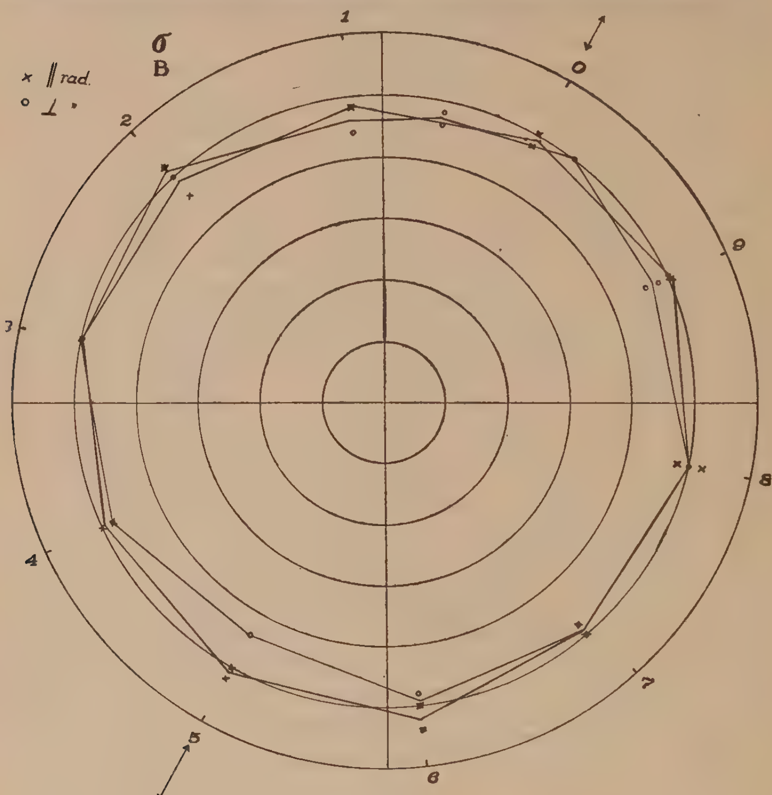

FIG. 8.

TABLE V.—*Electrical Resistivity.*

Steel.	Temperature. Degrees Cent.	Thomson Bridge. Microhms per Centimetre.	C. B. Bridge. Average Microhms per Centimetre.	Calculated. Microhms per Centimetre.
A	(*circa* 21)	18·58	18·27	17·5
	21·0	18·52	...	...
B	(*circa* 21)	19·51	18·47	18·6
	21·2	19·22	...	...

Macrostructure and Microstructure.

The specimens used in the two preceding sections were polished and carefully etched with Fry's [5] reagent (acid ammonium copper chloride), they were then photographed with normal illumination, the lighting being made as even as possible.

As seen from Fig. 10 (Plate XIII.), the etching of steel A varies rather markedly. Micrographs taken at 100 diameters near the white mark (showing the direction of elongation on rolling) and near the periphery at 90° to the right gave evidence that the latter was lower in carbon. That heterogeneity corresponded quite well with the variations of the electrical resistivity observed; the variation in carbon content did not, however, seem to be very considerable.

On the other hand, as seen from Fig. 11, the macrostructure of steel B must be said to be rather uniform, and micro-examination at 100 diameters revealed no greater variation in the microstructure. This steel might be said to be nearly as homogeneous as could be demanded. This is in harmony with the diagrams in Figs. 6 and 8, where the variations are much less than in Figs. 5 and 7.

Consequently, heterogeneities were likewise observed in the structure of the steels; they were not, however, very conspicuous in themselves.

General Discussion.

It has been shown that the stupendous variations in the temperature gradient on the same diameter of a regular sphere encountered in the first experiment were entirely supported by the precision method finally worked out, where in one case a ratio as irregular as 1 : 8·5 was found. The occurrence of these variations was further supported by thermoscopic observations and by actual measurements of the temperature distribution. It was further established that similar irregularities occurred in electrical resistivity, though on a much smaller scale: they were found not to exceed the ratio 1 : 1·05. Finally the macrostructure also showed some irregularities, though not very prominently. Consequently *the (apparent) variations in the thermal conductivity are of quite another order of magnitude than those of the electrical*

conductivity, in spite of the general belief at least in their approximate proportionality. Hence there is an unmistakable discrepancy between the views generally accepted and the actual experimental results.

Since the heat conduction in metallic masses is of considerable practical importance, the scientific elucidation of this discrepancy must likewise be considered to possess a practical interest, and will be briefly considered here.

As a matter of fact, the unexpected irregularities in heat conduction now established seem to stand in close relation to the results of a previous paper by Benedicks,[(6)] in which it was demonstrated that, contrary to the prevalent opinion of modern physicists, but in harmony with views of an earlier date,[(7)] thermo-electric currents do occur in every homogeneous circuit when unsymmetrically heated.* These electrical currents, which probably may assume very considerable intensities inside a solid metal, necessarily occasion an electrical transportation of heat, as is well known from the Thomson effect. In a later work [(8)] it was shown that such an electrical heat transfer does appear even in a homogeneous metal where primarily no temperature gradient occurs.†

Now, on account of these results, in the paper first referred to, stress was laid on the fact that the "thermal conductivity," as observed in a solid metal, must represent two independent phenomena—(i) purely thermal, and (ii) thermo-electrical.

(i) The *purely thermal* conductivity corresponds to the heat conductivity of any body not conducting electricity, *e.g.* rock crystal. Here the heat transfer must be explained as resulting from the continual collisions of the atoms.[(9)]

(ii) The *thermo-electrical* conductivity. Even in a homogeneous metal, and much more in a heterogeneous metal, strong electrical eddy currents will appear on unequal distribution of the temperature, having such directions as to facilitate heat transfer by the Thomson effect (or the general electro-thermic effect). This part

* This effect has been designated as the thermo-electric Benedicks effect. *See* E. Rumpf, *Physikalische Zeitschrift*, 1923, vol. xxiv. p. 437 ; 1924, vol. xxv. p. 400. C. Benedicks and G. Phragmén, *Arkiv för Matematik, Astronomi och Fysik*, 1925, vol. 19B, No. 4.

† This was described as the "homogeneous electro-thermic effect," comprising the Thomson effect as a special case.

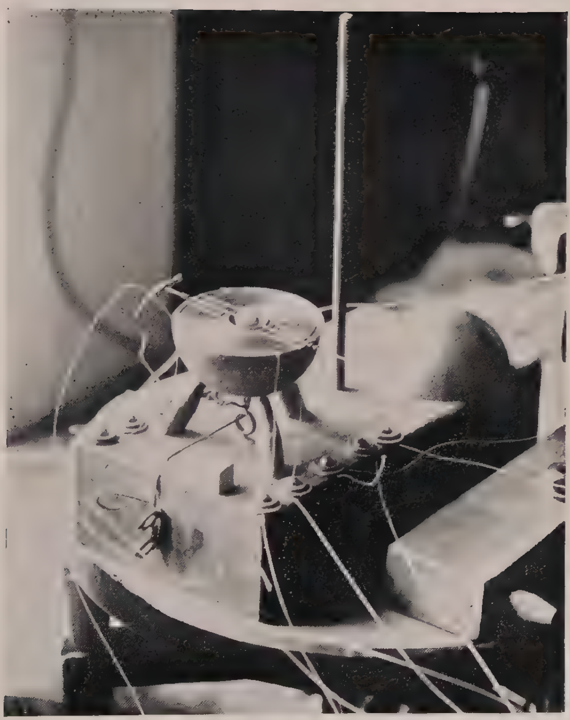

FIG. 9.—Showing the arrangement of the thermo-couples and other details of the sphere used in the spherical method of determination of heat conduction.

[To face p. 144

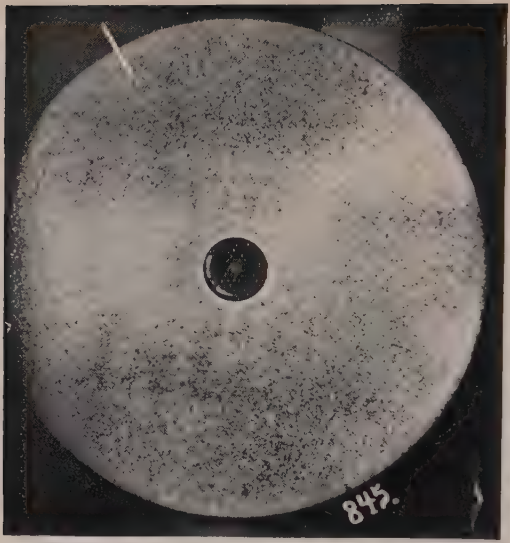

FIG. 10.—Macro-etching of Steel A ×2.
(Reduced to three-quarters.)

FIG. 11.—Macrostructure of Steel B. ×2.
(Reduced to three-quarters.)

of the heat conductivity must be high for a metal possessing (i) a high electrical conductivity, and (ii) a high Thomson coefficient. It is very characteristic that lead, for which metal the Thomson coefficient is (sensibly) zero, has the lowest thermal conductivity of all metals proper. Thus lead seems to possess a purely thermal conductivity. From this very low value, the heat conductivity of the other metals increases with increasing electrical conductivity, and with increasing Thomson coefficient, a fact which was observed, but not explained, by Radakowits.(10) It was shown by careful experiments that by an insulated subdivision of a copper wire its thermal conductivity decreases, the electrical conductivity being unimpaired.

If it be admitted, as a consequence, that a considerable part of the heat conductivity of, say, carbon steel, is due to an inner thermo-electric heat transfer, it is easily understood that *even small heterogeneities* will be able to exert a very considerable influence on these thermo-electric currents, and may easily direct them into special preferential paths. Thus, even comparatively very slight variations in electrical conductivity (and Thomson coefficient) may cause considerable variations in temperature, when the dimensions of the metal are considerable; a thin cylinder will be much less affected by these irregularities.

From a practical point of view, there are two items to be specially considered. On the one hand, the mechanism of heat conduction in a massive steel piece which we must postulate, will cause temperature irregularities of a possibly unfavourable character, especially as regards corrosion. On the other hand, the total heat transfer increases considerably with increasing dimensions of the metallic object, on account of this electrical heat convection. Strangely enough, there seems to be a rather close analogy with the heat transfer in liquids. Their heat conductivity proper is known to be very poor, and may only be observed if convection currents are carefully avoided; on the other hand, in a large fluid mass, there will be very strong convection currents transferring much more heat, though necessarily in a rather irregular manner. In an analogous way the electrical convection currents will increase in importance with the dimensions of the metallic object. Under given circumstances this might be quite a desirable property.

From this the following final conclusion is reached: the very considerable, though unexpected, variations in temperature observed in steel spheres in the previous investigation are readily understood from the standpoint taken in the previous work—namely that *a very considerable portion of the thermal conductivity of a metal consists in a heat transfer occasioned by thermo-electrical convection currents.*

Measurements on Cylinders.

It has been established by the previous work that a centrally heated sphere can hardly be used in order to determine the "heat conductivity" of a carbon steel; as a matter of fact, in such a sphere the heat conduction has been found to be dependent in a very capricious way on the slightest heterogeneities. However, in view of the primary object being simply that of determining λ for the two steels considered, it was decided to carry out further determinations on two cylinders turned out of the same samples (length, 200 millimetres; diameter, 8·0 millimetres). The method used was the following: the heat was generated in a short heating coil placed at the centre of the cylinder, the ends of which were water-cooled; any external heat loss was eliminated by using a guard cylinder heated separately to the same temperatures. This method, which will be described later in more detail, presents the considerable advantage, as compared with the Kohlrausch method, of giving a linear temperature gradient, which permits the checking of the method in itself.

The result is given in Table VI.:

Table VI.

Mark.	Carbon per Cent.	Q. Calorie per Second.	θ. Degrees Cent.	θ_1. Degrees Cent.	θ_2. Degrees Cent.	θ_m. Degrees Cent.	λ. Cal./cm. sec. Grade.
A	0·50	0·349	36·9	12·97	12·31	12·64	0·132
	,,	0·668	46·9	23·19	25·30	24·25	0·131
							0·132
B	0·71	0·580	40·2	13·89	15·78	14·84	0·124
							0·124

In this table θ represents the mean temperature of the zone measured, and θ_1, θ_2, and θ_m, represent the temperature differences on either side of the centre, and their mean value respectively; these values have been used for the calculation of λ. As seen from these figures, considerable irregularities do occur even when the specimens have a cylindrical form, but in spite of this, the average figures may claim a rather high accuracy.

The conduction value for steel *B* is found to be decidedly lower than for steel *A*, which conforms to the previous results. Both values obtained in this way agree well with those of previous workers.

Summary of Part I.

1. A method was successfully worked out for the accurate determination of small temperature differences, using a differential galvanometer with full compensation.

2. By this method local variations in the temperature differences were found to occur in spherical steel specimens, which were centrally heated. These variations were so considerable, in one case extending from 1 to 8·5, that there could be no question of using the spherical method, otherwise the least objectionable of all for determining heat conductivity, in the case of ordinary metals.

3. The occurrence of these variations was corroborated by other methods (thermoscopic, and direct measurements in several directions); they were found also to occur in electrical resistivity, though to a much smaller degree (variation 1 to 1·05). The microstructure also showed some variations; in one case at least, however, these were rather insignificant.

4. The paradoxical fact that the local variations in (apparent) heat conductivity are far more considerable than the variations in electrical conductivity or other properties, is elucidated by a previous investigation by one of the authors. It was found there that the apparent heat conductivity of a metal, even when as homogeneous as possible, must be due to a very great extent to thermo-electrical convection currents, which cause a considerable additional heat transfer by the Thomson effect (or by the "general electro-thermic effect").

5. If, in the small specimens generally used in the laboratory,

this electrical heat transfer is not so prominent—a subdivision, however, diminishes the thermal conductivity—its effect must increase considerably in larger masses. It will result not only in an unequal temperature distribution, but also in a heat transfer comparatively higher than that observed in small specimens.

As in gases and liquids where the heat transfer is essentially due to material convection currents, so the heat transfer in a solid metal seems essentially to depend on electrical convection currents.

6. Some determinations finally carried out on cylindrical specimens of the same steels showed also irregularities, it is true, but these were not very considerable.

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(9) C. Benedicks: *Jahrbuch der Radioaktivität und Elektronik*, 1916, vol. xiii. p. 351.

(10) J. Radakowits, *Physikalische Zeitschrift*, 1907, vol. viii. p. 505.

PART II.—THERMAL AND ELECTRICAL CONDUCTIVITY OF IRON AND CARBON STEELS.

By C. BENEDICKS and H. BÄCKSTRÖM.

Introduction.

In spite of its considerable practical importance, the study of the thermal conductivity of metals has received much less attention than that of the electrical conductivity, the reason obviously

being that its determination presents difficulties not met with in the determination of the electrical conductivity—viz. the overcoming of the transfer of heat by radiation and convection—the "external conduction."

In order to find a satisfactory means of eliminating this source of error we attempted, seven years ago, to work out a method in which a guard-tube surrounded the cylindrical specimen used. Both were heated electrically—on the one side to exactly the same temperature, by separate elements, while the other ends were cooled to the same temperature. This method was used for the determination of the heat conductivity of carbon steel specimens which had previously been investigated in detail in other respects. These determinations having been carried out, some doubt arose as to the strict correctness of the figures obtained; hence they were not published.

Meanwhile, another method which likewise employed a guard-tube was used by T. Simidu.[1] From his published figures, however, it did not seem to us that his method was more accurate. In order to arrive at some quite trustworthy results, where the external heat transfer could not possibly introduce any error, it was resolved to examine the applicability of a spherical method—hemispheres and cylinders being made of identically the same steels. However, as explained in Part I. of this paper, this method was found to be impracticable, on account of some paradoxical anomalies in heat conduction.

Returning consequently to cylindrical specimens, on the proposal of P. Sederholm, the original method was considerably improved: the guard-mantle was made quite symmetric, the specimens being heated in their central part. By means of a series of determinations on the same steel specimens, Sederholm obtained the desired correction, which could be applied to the figures previously obtained.

The final results—which may be considered as reliable—deviate considerably from some earlier ones, especially those for nearly pure iron.

The results are discussed also with regard to the electrical conductivity, and the influence of foreign elements.

[1] T. Simidu, *Science Reports, Tôhoku Imperial University*, 1917, vol. vi. p. 111.

Principle of the Guard-Tube Method.

A metal cylinder is heated at one end by a resistance coil (giving Q calories per second), while the other end is cooled. The specimen (of section S) is surrounded by a guard-tube, supposed to possess sensibly the same temperature as the cylinder. The stationary temperature gradient $\frac{\theta_1 - \theta_2}{(l_2 - l_1)}$ of the specimen having been measured, the heat conductivity λ, from the basic formula—

$$Q = \lambda \,.\, S \,.\, \frac{\theta_1 - \theta_2}{l_2 - l_1},$$

is directly obtained as

$$\lambda = \frac{l_2 - l_1}{S} \cdot \frac{Q}{\theta_1 - \theta_2}.$$

The advantage of this method—provided the guard-tube fulfils the desired object of thoroughly avoiding any external heat loss—is that the temperature fall, for the essential part of the cylinder, will be a linear one. This being easy to check, it is possible to control the correct functioning of the guard-tube much more easily than by the Kohlrausch method, as used by Simidu, where the temperature distribution follows a parabola.

It may be added that a guard-tube arrangement had been used already by A. Berget.[1]

Apparatus Used.

The upper end of the cylindrical specimen A (Fig. 12)—length, 200·0 millimetres; diameter, 8·0 millimetres—fits into a copper heater B (outer diameter, 13 millimetres; height, 16 millimetres). This is surrounded by an external heater C; D is an insulating layer (fibre). Into C fits a copper tube E (outer diameter, 19 millimetres; thickness, 1·5 millimetre), which is divided longitudinally; through a narrow vertical slit the thermocouples F_1, F_2, may be introduced. Their junctions are soldered into narrow copper rings, which stand in metallic contact with A, the temperature being measured with a differential galvanometer.[2]

[1] A. Berget, *Journal de Physique*, 1888, (2), vol. vii. p. 503; 1890, vol. ix. p. 135; *Comptes Rendus*, 1888, vol. cvi. p. 287. A method similar to that of Berget was used recently by J. W. Donaldson, *Journal of the Institute of Metals*, 1925, No. 2, p. 43.

[2] C. Benedicks, *Comptes Rendus*, 1916, vol. clxii. p. 979.

The lower parts of A and E fit into a cylindrical copper block G (25×44 millimetres), soldered into a radiating disc H (diameter, 150 millimetres); the details of this part are to be seen in Fig. 13.

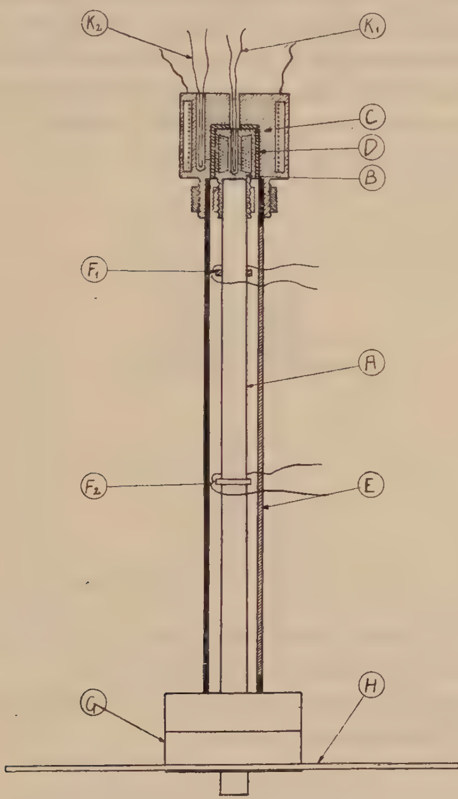

FIG. 12.—Apparatus for the Determination of Thermal Conductivity.

Finally, two narrow holes were provided in B and C for the introduction of the thermocouples K_1 and K_2, permitting, by means of a sensitive galvanometer, the control of the temperature difference, or equality, in B and C.

The current i passing through the heating coil B was read on a precision ammeter. As the resistance of B (constantan) was constantly $127 \cdot 5$ ohms, no current determination of the voltage

was made. Thus, i being expressed in amperes, the heating effect Q was obtained by the use of the formula:

$$0 \cdot 2388 \times 127 \cdot 5 \times i^2 \text{ grammes cal./sec.}$$

The current y passing through the outer constantan coil in C (resistance 71·5 ohms) was read on an ordinary ammeter.

The current was supplied from a 40-volt storage battery.

The galvanometer was a differential microgalvanometer of C. Benedicks' construction, with objective readings; 1 millimetre at a distance of 2 metres corresponded to about 5×10^{-8} volts,

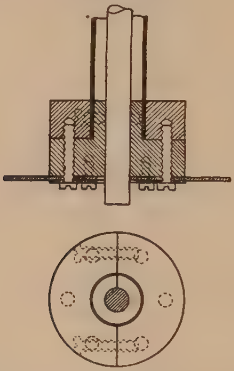

Fig. 13.—Lower Part of Fig. 12.

one winding being used (resistance 9 ohms). It was used, however, with a resistance of 100 ohms in each circuit.

The thermocouples used were made of 0·2 copper-constantan wire and were carefully calibrated.

Course of a Determination.

The procedure was as follows:

The sheathings of the thermocouples F_1, F_2 (Fig. 12), being fixed on to the cylinder, at a distance $l_2 - l_1$, the free mean distance l_0 from the heating coil B was also measured. The lower end of the cylinder was then introduced into the block G as well as the guard-tube E, and the cylinder was adjusted so that its upper edge was brought level with that of the mantle, and the screws in G were tightened. The external heater C was now pushed over the inner one B, so as to embrace also the upper part of

the guard-tube; the screw nut at this place having been tightened, the apparatus was ready for use.

The course of an experiment was the following: A constant current being sent through the inner heater B, the current in the outer heating coil C was successively adjusted so that equality of temperature in B and C resulted. A stationary state being reached, the temperature difference $\theta_1 - \theta_2$ was determined and λ obtained from the formula already given.

Some Preliminary Tests of the Method.

First, the time necessary to establish a steady temperature was ascertained. A steel cylinder being introduced with heating

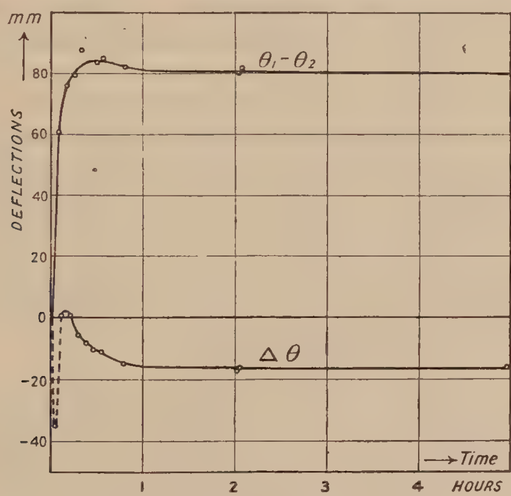

Fig. 14.—Temperature-Time Curves.

currents in B, $i = 0 \cdot 100$ ampere, and in C, $y = 0 \cdot 370$ ampere, the galvanometer deflections were read corresponding with $\theta_1 - \theta_2$, that is, with the difference $\Delta\theta$ between the temperature in the heaters B and C. The result is graphically represented in Fig. 14.

It will be seen that a steady temperature is practically reached after the lapse of only one hour. In the final determinations, however, three hours were allowed to pass before the readings were taken.

For the purpose of ascertaining how far the temperature of a point on the guard-tube could be made to coincide with that

on the specimen, the two junctions of a copper-constantan thermocouple, fixed on a flexible cardboard, were gently pressed, the one against the inner side of the mantle, the other against the opposite point of the cylinder; the piece of cardboard could be moved along the specimen so as to vary the distance l_0. The thermocouple was connected with the galvanometer across a resistance of 207 ohms.

The figures obtained are shown graphically in Fig. 15, for varying intensities of the current in the inner coil i, and in the outer coil y.

Whenever the temperature difference for $l_0 = 0$, or $\Delta\theta$, is considerable, the difference between cylinder and guard-tube is seen likewise to be considerable: if the external heater has too high a temperature ($\Delta\theta > 0$), the difference between cylinder and mantle goes in the opposite direction (Fig. 15A, B); if the external heater has too low a temperature ($\Delta\theta < 0$), the difference in the other direction is also considerable (Fig. 15E). In the intermediate case, when $\Delta\theta$ has nearly disappeared, the temperature difference between cylinder and mantle is very small (Fig. 15C). Fig. 15D would seem to represent the ideal case of no sensible temperature difference at all. Here, however, no external current was used ($y = 0$), and the temperature similarity no doubt is due to some leakage from the inner heater to the external one (for final correction of this, see later).

It is not quite easy to adjust the external heating current so as to give strictly $\Delta\theta = 0$. But even in the case where $\Delta\theta$ does not vanish, an "apparent conductivity," λ_a, may be calculated from the formula. Now, λ_a must be a function of $\Delta\theta$. This is evidenced by Fig. 16, giving λ_a as obtained (in a stationary way) with a constant heating current $i = 0{\cdot}0980$ ampere, but with five values y varying from $0{\cdot}370$ to $0{\cdot}300$ ampere. There is apparently a linear relation between λ_a and $\Delta\theta$. The λ_a value for $\Delta\theta = 0$, designated here as λ_0, may be interpolated with considerable accuracy.

In order to check the correct function of the guard-tube some determinations were undertaken in the following two directions:

(1) Under conditions otherwise constant, the mean distance

$$l_0 = \frac{l_1 + l_2}{2}$$

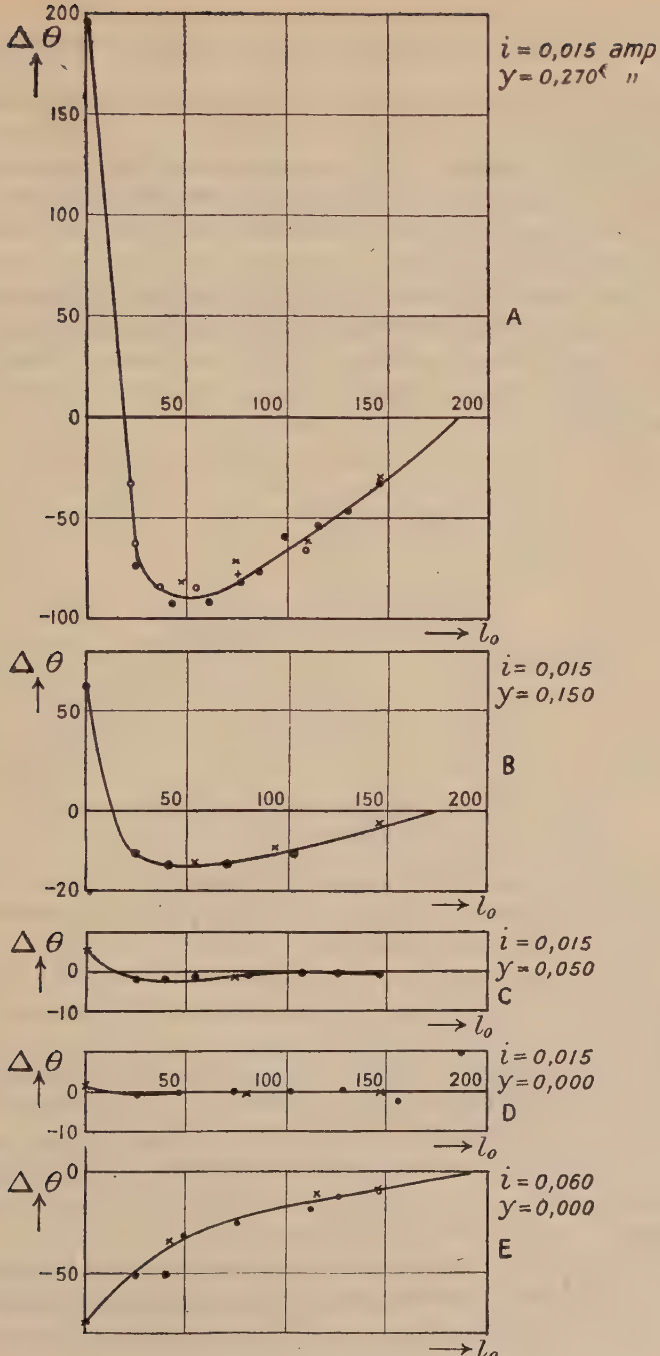

FIG. 15.—Temperature Differences between Specimen and Guard-Tube.

was varied. (2) Guard-tubes of different length and material were used.

The figures obtained for a given steel cylinder are represented in Fig. 17. The distance $l_2 - l_1$ was about 4·50 centimetres.

It will be seen that the relation between λ_0 and the average distance l_0 is a linear one.

In the case of no guard-tube being used (line *a*), the external heat losses are quite considerable, and the λ_0 values are much too high. Using a long guard-tube (*b*) the heat losses evidently are much reduced, and this is still more the case when a short tube is used (*c*).[1]

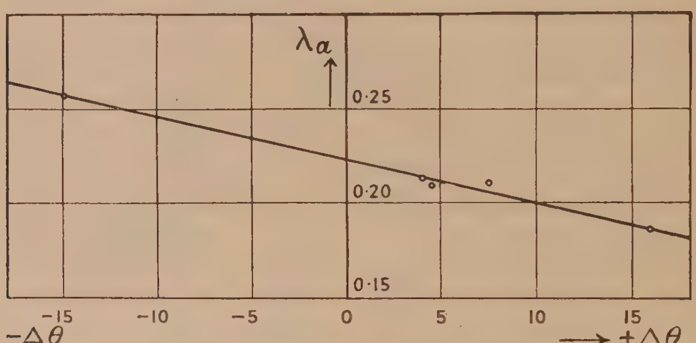

FIG. 16.—"Apparent Thermal Conductivity" as a Function of Temperature Difference.

Though, generally, the copper guard-tubes give lower values than the iron ones, the difference is not very clearly observable.

We may infer from this that:

1. In the case of no guard-tube being used, very considerable errors in λ_0 occur, the conductivities as measured being much too high.

2. Even the use of the shortest guard-tubes—which are the most effective ones—does not in itself warrant a correct value.

3. It is evident, however, that the lines of the different series in Fig. 17 *a*, *b*, *c*, intersect each other at the same point, having the abscissa $l_0 = 0$; this point giving here $\lambda = 0·117$ cal./cm. sec. Grade.

This value must be the same as that which would be obtained if all side losses were eliminated (as indicated by the schematic

[1] The lower end of the cylinder then projected below the copper block.

line *d*). Provided the heating effect, received by the cylinder in the section $l_0 = 0$, did coincide with the actual heating effect Q, these extrapolated values—designated here as λ—no doubt would be fairly correct, in spite of the fact that the guard-tubes as used so far do not entirely protect from side loss.

Some determinations were made, for the sake of control, on a cylinder of commercial copper (200 × 8 millimetres).

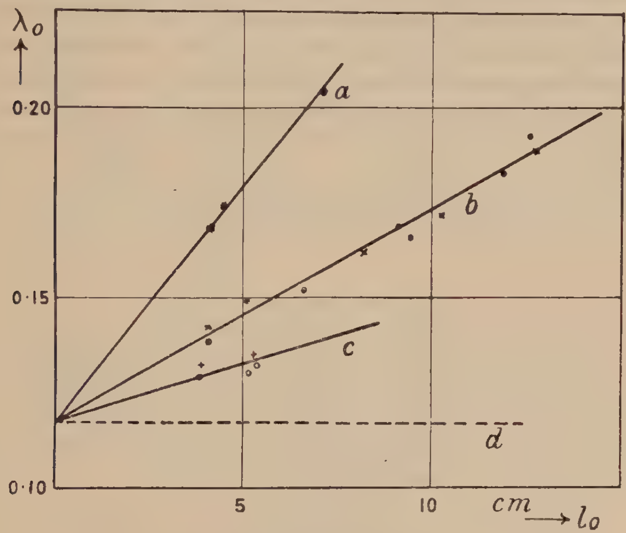

FIG. 17.—Thermal Conductivity of Steel Cylinder under Different Conditions.

a, No guard-tube.
b, 18 cm. iron (●) or copper (×) guard-tube.
c, 9 cm. iron (○) or copper (+) guard-tube.
d, No external heat loss.

The results obtained are compiled in Fig. 18.

It is seen that the points obtained for the copper cylinder when surrounded by the long copper guard-tube lie almost exactly on a horizontal line *c*. The value given by this, or $\lambda = 0{\cdot}870$, coincides fairly well with earlier values for copper, such as 0·891 found by Jaeger and Diesselhorst.[1]

Further, we see that in this case even the copper cylinder without being surrounded by any guard-tube has given values (*b*) very near to the former line. Finally, when an iron mantle was used, the values obtained were still somewhat higher (*a*).

[1] Landolt-Börnstein, "Phys.-chem. Tab." (5. Auflage. Berlin, 1923), p. 1291.

This behaviour lent support to the admissibility of the extrapolation referred to.

Hence, the method as described was considered as having been sufficiently well checked, at least for a first set of determinations, and was adopted for the purpose of measuring λ for carbon steels.

Regarding the use of the method it may be remarked that, from Fig. 17, it would perhaps seem most appropriate to use a shorter guard-tube (9 centimetres), as this was found to give values of λ approaching more to the final value than those

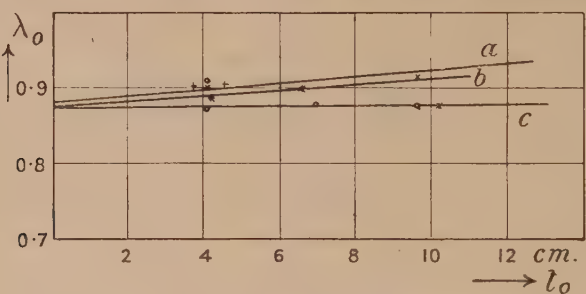

Fig. 18.—Thermal Conductivity of Copper Cylinder under Different Conditions.

a, Iron mantle.
b, No mantle.
c, Copper mantle.

obtained with the longer tubes (18 centimetres). The use of the latter, however, was preferable, on account of the greater reliability of the extrapolation then gained, the length along which determinations were made being rather more extended as compared with the extrapolation length.

On a subsequent detailed examination of the conduction apparatus used it was found, however, that even when no temperature difference was indicated by the thermocouples K_1, K_2 (Fig. 12), some parasitic heat transmission from the inner heater B to the external one C took place; this was apparently due to the outer surface of B not being isothermic, on account of the one-sided heat transmission by the specimen A. The fact that the apparatus had given fairly satisfactory results in the case of copper cannot be considered as a strict proof of its correct-

ness in the case of iron or steel, where the external losses are necessarily much higher, the conductivity being only about one-seventh of that of the copper.

Now, the source of error mentioned, as pointed out by Sederholm, may be avoided, if the apparatus is symmetrically constructed, and the measuring device as used will be described by him in a subsequent paper. A strictly linear temperature gradient was obtained in the part of the cylinder tested; since, on account of the symmetry, no parasitic heat transfer could possibly occur, the results obtained must be quite trustworthy. New determinations having been carried out in this way on seven of the steel specimens, a correction curve was obtained, which has been used here. After this correction the primary values may be relied upon. In the following, the primary values are given as well as the corrected ones.

Experimental Results.

As already pointed out, the material to be used belonged to that previously examined in detail by C. Benedicks.[1]

The composition of these carbon steels 1 to 8, produced in the Kjellin induction furnace at Gysinge, is given in the following table, where two other steels of unknown process (A, B) are also given.

Table VII.—*Composition of Carbon Steels Used.*

Gysinge, 1–8; Unknown Process, A, B.

Mark.	Carbon. Per Cent.	Silicon. Per Cent.	Manganese. Per Cent.	Sulphur. Per Cent.	Phosphorus. Per Cent.
1	0·08	0·03	0·13	0·005	0·009
2	0·45	0·65	0·35	0·02	0·015
3	0·55	0·86	0·44	0·02	0·014
4	0·90	0·28	0·41	0·015	0·014
5	1·20	0·30	0·44	0·01	0·014
6	1·35	0·26	0·54	0·015	0·014
7	1·50	0·12	0·29	0·02	0·013
8	1·70	0·08	0·29	0·03	0·013
A	0·50	0·24	0·32	...	...
B	0·71	0·24	0·18	...	...

[1] Doctor's thesis, "Recherches physiques et physico-chimiques sur l'acier au carbone." Upsala, 1904.

Generally, each carbon content was represented by three cylinders, say, 5.1, 5.2, 5.3. Of these the suffix number 1 indicated annealed specimens; number 2, specimens as forged; and 3, annealed specimens which subsequently had been hardened at 800° C. (then designated, say, as 5.3*h*).

The electrical resistivity of these steels had been carefully determined in 1900, using a method which is described in Benedicks' thesis. By means of a Thomson bridge from Hartmann and Braun, determinations were made by H. Bäckström in 1919. Finally, with the same instrument, new determinations were made by P. Sederholm in 1926. For the hardened specimens, as was to be expected, a decrease of the resistivity was found to have taken place successively, as shown by the following table:

TABLE VIII.—*Secular Variations in Electrical Resistivity in Microhm-Centimetres at about* + 18° *C.*

No.	Benedicks, 1900.	Bäckström, 1919.	Sederholm, 1926.
1.1	10·51	10·6	10·55
1.2	10·72	...	10·69
1.3*h*	10·90	10·6	10·79
2.1	24·03	23·2	23·94
2.2	23·76		23·52
2.3*h*	28·99	27·9	28·33
3.2	27·68	27·7	28·26
3.3*h*	34·36	32·9	32·90
4.1	20·44	20·3	20·44
4.2*h*	36·94	32·2	32·16
4.3	20·02	...	...
5.1	20·99	20·9	20·90
5.2	20·80		21·10
5.3*h*	42·13	36·8	36·38
6.1	21·70	21·7	21·91
6.2	21·75		21·86
6.3*h*	44·35	39·6	39·25
7.1	17·85	17·9	18·21
7.2	18·24		18·59
7.3	17·72		17·61
8.1	17·72	17·8	17·76
8.2	17·68		18·20

The figures obtained on the quenched specimens are plotted in Fig. 19.

It will be seen from this that a considerable decrease in resistivity had occurred—which must be considered when dealing

with the heat conductivity. The curves are drawn taking account of the result obtained on reheating at higher temperatures by C. F. Rydberg.[1]

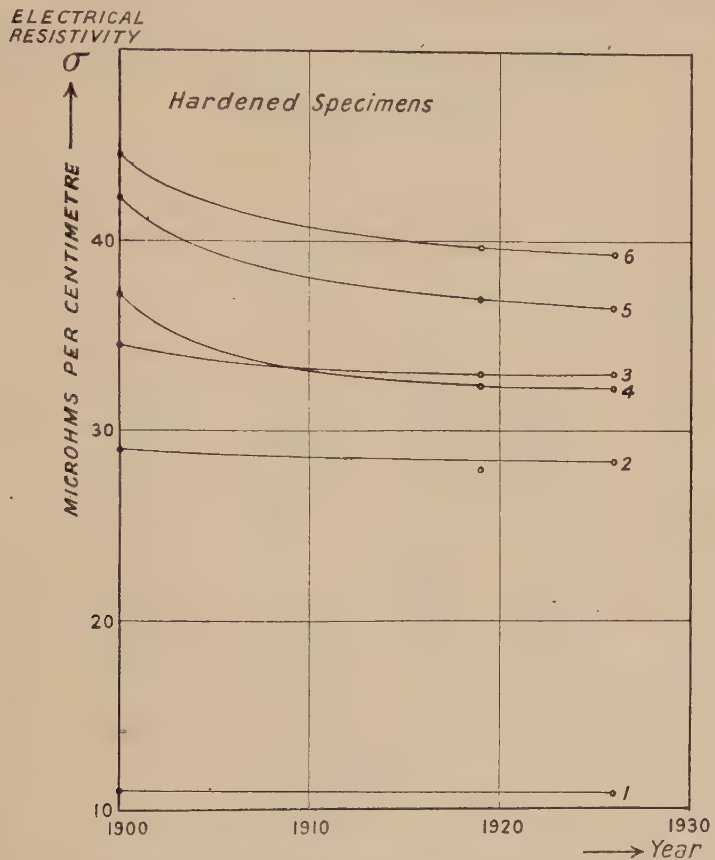

Fig. 19.—Secular Variations in Electrical Resistivity of Hardened Steels.

The determinations of the heat conductivity are given in Table IX. Here λ_1 are the values directly obtained, using the previous method. In the third column are entered the corresponding values after applying the correction; λ_2 are the determinations executed by Sederholm. Finally, the inverse values,

[1] C. F. Rydberg, *Bih. t. K. Svenska Vet.-Akad. Handl.* 13, I., No. 6 (1887).

or thermal resistivities, are given, being more rational functions for discussion than conductivities, in the same way as the electrical resistivity of solid solutions is more rational to discuss than the electrical conductivity.

TABLE IX.—*Thermal Conductivity and Resistivity of Carbon Steels.*

Cylinders, 200 × 8 *millimetres.*
Mean temperature, + 40° *C.*

No.	λ_1.	λ_1. Corr.	λ_2.	$1/\lambda_1$. Corr.	$1/\lambda_2$.
1.1	0·223	0·188	0·1877	5·32	5·32
1.2	...	...	0·1872	...	5·34
1.3*h*	...	...	0·1825	...	5·48
2.1	0·147	0·112	0·1139	8·93	8·77
2.2	0·145	0·110	...	9·09	...
2.3*h*	0·118	0·087	...	11·49	...
2.4	...	...	...	...	...
3.2	0·120	0·089	0·0971	11·24	10·30
3.3*h*	0·105	0·078	...	12·82	...
4.1	0·149	0·113	0·1060	8·85	9·44
4.2*h*	0·109	0·081	...	12·35	...
4.3	...	...	...	...	...
5.1	0·145	0·110	...	9·09	...
5.2	0·146	0·111	...	9·01	...
5.3*h*	0·088	0·065	0·0745	15·38	13·42
6.1	0·129	0·096	...	10·41	...
6.2	0·140	0·106	...	9·43	...
6.3*h*	0·099	0·073	0·0537	13·70	18·62
7.1	0·159	0·122	...	8·20	...
7.2	0·159	0·122	...	8·20	...
7.3	0·157	0·120	...	8·33	...
8.1	0·165	0·127	0·1221	7·87	8·19
8.2	0·159	0·122	...	8·20	...
A	...	...	0·1316	...	7·60
B	...	...	0·1245	...	8·03

The thermal resistivity figures are graphically represented as ordinates in Fig. 20; as abscissæ are used the corresponding electrical resistivity as given in Table VIII.

DISCUSSION OF THE EXPERIMENTAL RESULTS.

As seen from Fig. 20, the observed points group themselves along a slightly bent curve (drawn as a straight line). Whether the deviations from this are due to experimental errors—which,

it is believed, are principally due to the deviations from a strictly geometrical shape of the specimens—or to inherent causes, is not ascertainable by means of the present observations.

Anyhow, *as a first approximation*, we are justified in saying

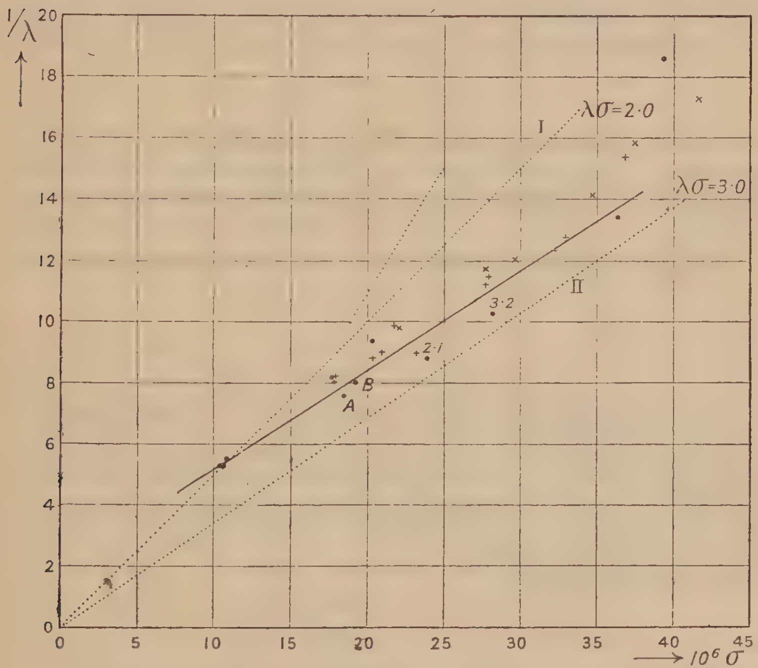

FIG. 20.—Thermal Resistivity Determinations in Carbon Steels.

+ = H. B., 1919.
• = P. S., 1926.
× = Campbell and Dowd.
Short dotted line = Simidu.

that there is a linear relation between the thermal resistivity and the electrical one. This is expressed by the formula—

$$\frac{1}{\lambda} = 1\cdot9 + 0\cdot325\sigma,$$

valid at least from $\sigma = 10$ to $\sigma = 40$ microhm-centimetres.

Now, according to the formula of C. Benedicks,

$$\sigma = 7\cdot6 + 26\cdot8\Sigma C,$$

it is known that the electrical resistivity σ, at least as a first

approximation, is a linear function of the sum ΣC of the *carbon values* of the elements in solid solution, *i.e.*

$$\Sigma C = C + \frac{12 \cdot 0}{28 \cdot 4} Si + \frac{12 \cdot 0}{55 \cdot 0} Mn + \ldots,$$

C, Si, Mn, designating the weight percentages of these elements.

By substituting this, we obtain from the previous formula,

$$\frac{1}{\lambda} = 4 \cdot 4 + 8 \cdot 7 \Sigma C,$$

where λ is expressed in cal./cm. sec. Grade, and C in weight per cent. Hence, this formula, as a first approximation, expresses the thermal resistivity of carbon steels as a function of the elements dissolved.

The formula obtained gives us for $\Sigma C = 0$, *i.e.* for pure iron,

$$\frac{1}{\lambda} = 4 \cdot 4,$$

or

$$\lambda = 0 \cdot 227 \text{ cal./cm. sec. Grade.}$$

Now, this presupposes the admissibility of extrapolating the formula for lower ΣC values than those actually observed. Objections have been made against the extrapolation (to $\Sigma C = 0$) of C. Benedicks' formula for σ, giving $\sigma = 7 \cdot 6$ microhm-centimetres. However, it has been established by F. C. Thompson [1] that a very pure rolled iron gave

$$\sigma = 7 \cdot 56.$$

In view of this, the above extrapolation seems to be equally justified.

The remarkable point, however, is that the values actually determined for the purest iron, containing 0·08 per cent. carbon, viz.:

$$\lambda = \begin{array}{l} 0 \cdot 1877 \\ 0 \cdot 1872 \\ \hline \end{array}$$

or, rounded off, say, $\quad 0 \cdot 187$ cal./cm. sec. Grade,

are considerably higher than the average figure recently derived by M. Jacob,[2] from a careful inspection of existing data, especially those of T. Simidu,[3] viz.:

$$\lambda = 0 \cdot 135 \text{ cal./cm. sec. Grade.}$$

---

[1] F. C. Thompson, *Philosophical Magazine*, 1916, vol. xxxi. p. 357.

[2] M. Jacob, *Zeitschrift für Metallkunde*, 1924, vol. xvi. p. 353; Landolt-Börnstein, "Physik.-chem. Tab.," 5. Auflage, Berlin, 1923.

[3] T. Simidu, *Science Reports, Tôhoku Imperial University*, 1917, vol. vi. p. 11.

This value, in our opinion, is about 50 per cent. too low. Much higher values have actually been obtained for iron by careful workers. Thus, J. D. Forbes[1] (1867) found $\lambda = 0 \cdot 207$, which is still below the above value for pure iron. Quite recently E. Sedström,[2] working on very pure electrolytic iron from Heraeus, obtained

$$\lambda = 0 \cdot 18.$$

Work of T. Simidu and of E. D. Campbell and W. C. Dowd.

The above formula for the thermal resistivity differs considerably from some formulæ given by T. Simidu,[3] *e.g.* the following, which is supposed to apply for quenched steels :

$$\lambda_2 = 0 \cdot 1284 - 0 \cdot 0310b - 0 \cdot 0308C,$$

where C signifies "percentage of carbon" and b the sum of the atomic percentages of manganese and silicon.

It must be remarked, however, that the algebraic form chosen by Simidu is quite unsuitable, since it is well established that the electrical resistivity is a linear function of dissolved substances to a much greater degree than the electrical conductivity, the same must be expected to hold true for the thermal magnitudes. If the above formula, which sums up our observations, is likewise written so that λ is given directly, it assumes the form

$$\lambda = 0 \cdot 227\,(1 - 1 \cdot 98\Sigma C + 3 \cdot 92\Sigma C^2 - \ldots).$$

It is evident from this, that with a content of $\Sigma C = 1$ per cent. the positive term—which is omitted by Simidu—has twice as large an influence as the negative term ; consequently, his formula is not admissible, except for very small percentages.

It must be remarked that the variation in the λ values observed by Simidu are actually very small—to such a degree that the calculated values in certain cases show a deviation amounting to two-thirds of the total amplitude of the variations in λ.

Unfortunately, the same holds true regarding Simidu's formulæ

[1] Landolt-Börnstein, "Physik.-chem. Tab." (5. Auflage. Berlin, 1923), p. 1290.

[2] E. Sedström, "Einige physikalische Eigenschaften metallischer Mischkristalle." Inaug. Diss. (Lund). Stockholm, 1924.

[3] T. Simidu, *loc. cit.*

for the electric resistivity: a difference between the observed and calculated values of $+2 \cdot 0$ and $-1 \cdot 8$, or an amplitude near $4 \cdot 0$, is considered as insignificant, though the total amplitude of σ lies between $17 \cdot 7$ and $24 \cdot 1$, giving a variation amplitude of only $6 \cdot 4$ microhms. The method of least squares, as used by Simidu, may give any result if the amplitude of the variation of the magnitude to be determined is not decidedly larger than the experimental errors.

Although the experimental method of Simidu seems to be a careful one, no results are given or mentioned which permit its proper working to be checked. On account of the low values obtained, M. Jacob in some cases applied a correction of $+15$ per cent.; a higher amount might be necessary. As seen in Fig. 20, Simidu's values deviate considerably from those obtained here [1] (short dotted line).

On the contrary, the determinations published by E. D. Campbell and W. C. Dowd [2] on some steels of widely different composition, show excellent agreement with the present results, as seen from Fig. 20, where Campbell and Dowd's thermal resistances are plotted. As they are only relative ones, the value (given as $1/\lambda = 1$) for the purest iron specimen ($\sigma = 10 \cdot 64$) has been made to coincide with the value ($1/\lambda = 5 \cdot 3$) found here for the purest specimen ($\sigma = 10 \cdot 55$).

"Constant" of Wiedemann-Franz' Law.

In Fig. 20 the straight line I is the expression of a Wiedemann-Franz product, $\lambda\sigma = 2 \cdot 0$, while the straight line II corresponds with $\lambda\sigma = 3 \cdot 0$. As seen from Fig. 20, all observed values, except those of Simidu, fall within these limits, but there is no possibility of deducing any constant value: obviously Wiedemann-Franz' law is merely a rough approximation.

[1] It should not be left out of consideration, however, that the very low λ values obtained by Simidu may be due to his using fairly thin cylinders (5 millimetres). As emphasised in Part I. of this paper, on account of the complex nature of the heat conduction, higher apparent figures are obtained in thicker specimens. Hence, the tremendous variations in λ found by different observers may not solely be due to experimental errors; they may be inherent in the conduction itself.

[2] E. D. Campbell and W. C. Dowd, *Journal of the Iron and Steel Institute*, 1917, No. II. p. 251.

Specific Influence of Added Elements.

So far, the thermal resistivity $1/\lambda$ has mainly been regarded as essentially a linear function of the electrical resistance.

However, the formula for σ of C. Benedicks cannot claim to be more than a first approximation—though in many cases fairly satisfactory. On detailed analysis of existing data, it was shown by C. Benedicks [1] in 1916, and later by A. L. Norbury,[2] that individual values may be ascribed to the different elements added—as had already been done by H. Le Chatelier.[3] Hence it seems natural to analyse further the individual influence on λ of foreign elements, such as silicon and manganese.

To some extent this has been attempted by Simidu; however, the insignificant variations in silicon (0·05–0·31 per cent.) and manganese (0·27–0·67 per cent.) permit of no definite conclusions. Nor can any definite conclusions as regards silicon and manganese be drawn from the present determinations. It must be remarked, however, that the two steels with a high silicon content (No. 2 with 0·65 per cent., No. 3 with 0·86 per cent.) have given figures lower than the average. Similarly, two steels containing silicon as high as 1·20 and 3·65 per cent. which were tested by Campbell and Dowd gave comparatively low values.

This would indicate that silicon increased the thermal resistance slightly *less* than the electrical resistance.

An 11·57 per cent. manganese steel likewise investigated by these authors gave values indicating that $1/\lambda$ is affected practically in the same proportion as σ.

Some experiments recently executed by E. Sedström [4] are all the more noteworthy, in view of the practical value of a steel exhibiting a high λ for certain work, such as boilers.

Sedström has determined λ for some iron alloys produced *in vacuo*, using a Heraeus electrolytic iron. His results are plotted in Fig. 21 as $1/\lambda$, and in atomic per cent.

From these curves we may deduce that 1 atomic per cent. of the added element increases the thermal resistance of iron by the following amounts (Table X., second column).

[1] C. Benedicks, *Jernkontorets Annaler*, 1916, p. 35.
[2] A. L. Norbury, *Transactions of the Faraday Society*, 1921, vol. xxvi. p. 570.
[3] H. Le Chatelier, "Contribution à l'étude des alliages" (1901), p. 416.
[4] E. Sedström, *loc. cit.*

TABLE X.

Added Element.	$\Delta 1/\lambda$.	$\Delta\sigma$.
Nickel . .	1·25	4·0
Manganese . .	1·9	6·0
(Carbon) . .	(1·9)	6·0–6·5
Aluminium .	2·3	6·4
Silicon . .	3·24	6·9
		6

These values for the increase in thermal resistance per atomic per cent. are very interesting, when compared with the increases of

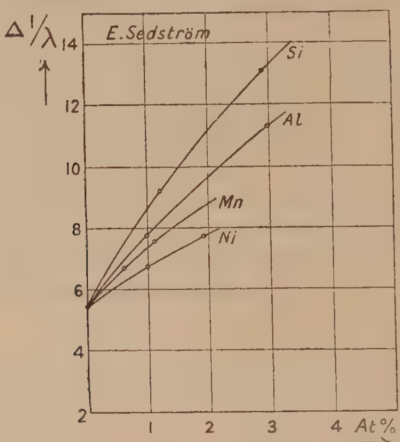

FIG. 21.—Increase in Thermal Resistivity due to Added Elements (Sedström).

the electrical resistivity of iron caused by 1 atomic per cent. of an added element, given in the third column; these are the values obtained by C. Benedicks [1] in 1916. The order of increase is seen to be the same in both columns. However, while the latter values ($\Delta\sigma$) do not differ much from a mean value of 6·0, the different increments in thermal resistance differ much more. This is illustrated in Fig. 22, where the thermal and electrical incre-

[1] *Loc. cit.*

ments are plotted (giving not only the above average values of $\Delta\sigma$, but also the extreme values observed for each element). This diagram indicates that the relation between $\Delta\sigma$ and $\Delta 1/\lambda$ is not a linear one; it seems actually to be of the second or even third degree, to judge by the curves drawn in Fig. 22.

This result differs considerably from our general conceptions—implying that σ is affected more than $1/\lambda$ by influencing factors. There seems, however, to be no reason for doubting the essential correctness of Sedström's determinations.

In Table X. we have also introduced the increase in thermal

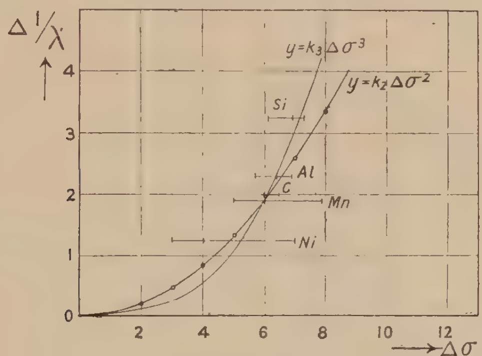

FIG. 22.—Relation between Increase in Thermal Resistivity and in Electrical Resistivity.

resistance caused by hardening carbon as calculated from the previous formula. As seen, this value coincides with that pertaining to 1 atomic per cent. of manganese.

The value for nickel seems to be in good agreement with K. Honda's[1] determinations on nickel steel, though the comparison is difficult, as Honda's figure for λ of pure iron is only half that of Sedström.

On the contrary, Sedström's figures ascribe to silicon a fairly high increase in the thermal as compared with the electrical resistivity. This is contrary to the indications referred to above, according to which silicon would give a rather small increase of $1/\lambda$.

[1] K. Honda, *Science Reports, Tôhoku Imperial University*, 1918, vol. vii. No. 1, p. 59.

Consequently, even if the influence of silicon is uncertain, a few points may be noted regarding the influence exerted by certain dissolved additions on the thermal conductivity of iron :

1. As a first approximation, 1 atomic per cent. of any dissolved element may be considered to exert the same influence—that of increasing the thermal resistivity $1/\lambda$ by about $1 \cdot 9$. However, some modifications of this general rule may be traced.

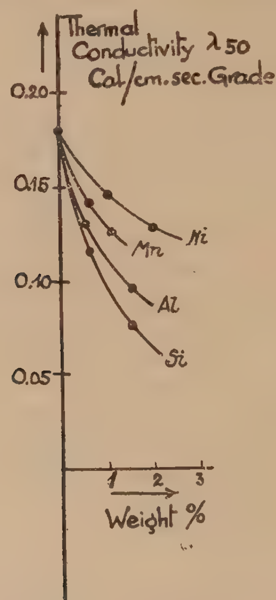

Fig. 23.—Decrease in Thermal Conductivity due to Added Elements (Sedström).

2. It may be stated, according to the consistent determinations of Honda and Sedström, that nickel increases $1/\lambda$ in a less degree than it increases σ. Consequently, in order to diminish the thermal conductivity as slightly as possible, *nickel* is probably the most suitable element to use.

3. Next to nickel, manganese is a preferable addition. The opinion, sometimes expressed, that manganese should diminish λ considerably, is not supported by any experimental data. Manganese does not lower λ more than the same atomic per cent. of

hardening carbon ; consequently, manganese lowers λ much less than the same percentage by weight of hardening carbon.

4. According to the figures of Sedström, aluminium lowers λ by a comparatively large amount, as would also be the case with silicon ; this, however, is not borne out by any other determinations. Anyhow, aluminium and silicon should both be low, their influence per weight per cent. being at least twice that of manganese. The influence of 1 per cent. by weight is further illustrated by Fig. 23, reproduced from Sedström's thesis.

5. Cementite carbon causes only a slight decrease of λ, as indicated particularly by the present determinations.

Summary of Part II.[1]

1. A method is described for the determination of thermal conductivity λ, in which a cylindrical specimen is heated electrically at one end and cooled at the other ; in order to eliminate external heat losses, a guard-tube is provided, which is heated—or should be heated—separately to exactly the same linear temperature distribution.

2. After having been tested in several directions, this method was used for determining λ in the carbon steel specimens which had been previously investigated by C. Benedicks. Afterwards, a certain correction was applied for a persistent one-sided heat loss ; for this purpose the method was improved by adopting a symmetrical arrangement, as will be described later (P. Sederholm).

3. For the sake of comparison, the electrical resistivity σ was determined ; a survey is given of the changes in σ of hardened specimens, occurring during a period of twenty-six years.

4. As a first approximation, a fairly close connection between thermal $(1/\lambda)$ and electrical (σ) resistivity was found to exist—though not corresponding with a constant Wiedemann-Franz product $\lambda\sigma$.

5. In accordance with this, the thermal resistivity of carbon steel may be expressed by the formula—

$$1/\lambda = 4 \cdot 4 + 8 \cdot 7\Sigma C,$$

where λ is expressed in cal./cm. sec. Grade and ΣC = carbon value in weight per cent. of added elements dissolved in the iron.

[1] For Summary of Part I. see p. 147.

6. This formula assigns to pure iron ($\Sigma C = 0$) the value

$$\lambda = 1/4 \cdot 4 = 0 \cdot 227 \text{ cal./cm. sec. Grade,}$$

which, hitherto, has not been obtained. At all events, the purest iron tested (0·08 per cent. carbon) gave as high a value as 0·187, which ought to replace the value sometimes given for pure iron, $\lambda = 0 \cdot 135$.

7. It was attempted, as a better approximation than that given by the formula, to discuss the individual influences exerted by some added elements. In spite of the scarcity of available data, it seems justifiable, regarding their influence on λ, to range the added dissolved elements in the following order (mainly due to E. Sedström): nickel, manganese, hardening carbon, aluminium, silicon, indicating that the thermal conductivity of iron is lowered least by 1 atomic per cent. of nickel, more by manganese, and so on. Cementite carbon exerts only a slight influence on λ.

8. As pointed out in Part I. of this paper, too much importance should not be attached to λ figures, as the property designated thermal conductivity is apparently a complex one, not independent of the dimensions of the specimens used.

DISCUSSION.

Professor C. H. Desch, D.Sc., F.R.S. (Member of Council), in opening the discussion, thought the paper contained observations of considerable interest, both from the practical point of view and also with regard to the theory of conduction, and probably the subject would have to be thrashed out very thoroughly by physicists before an explanation of the remarkable facts elicited could be devised. The authors had found certain irregularities of distribution. He was not quite sure from the record whether, on repeating a set of tests on the same specimen, the irregularities had always been distributed in the same way; whether the ellipse, for example, always had its major axis in the same direction.

Professor Benedicks, interposing, said it had.

Professor Desch, continuing, said the suggestion was made in the paper that there was a kind of convection current—he supposed an electronic convection current—of the metal corresponding to the convection currents in liquids and gases. Those were determined in position by very slight irregularities. Their distribution might be almost a chance one, and it might be expected that, if it were a question of convection, variations would occur between different experiments. It seemed to be quite clear that the mechanism of thermal conduction was much more complicated than that of electrical conduction, but, unfortunately, very much was not yet known about the mechanism of electrical conduction: it was still a highly controversial matter in physics.

With regard to the practical applications, the peculiar effect which was found in spheres would become very much smaller when dealing either with cylinders or with large plates, in which the transfer of heat would take place, he supposed, very much in accordance with ordinary ideas of the flow of heat through a rectangular plate. In that case the only effect of those peculiarities of conduction would be to alter the value of the coefficient of thermal conductivity, but as that could be determined empirically in the laboratory, he imagined that the practical consequences would not be so very great.

The authors made a reference to the influence of corrosion, from which the speaker gathered that they thought there would be local irregularities of temperature. If that were so, it should be possible to recognise those local differences of temperature in the case of conduction through an ordinary plate, and he would like to know whether any observations of that kind had been made. He gathered from the paper that cylinders gave very much more uniform results than spheres, and

he imagined that plates would be more uniform still, in which case the influence of corrosion, he thought, would be negligible. Whatever the interpretation might be, the facts were extraordinarily interesting, and the authors had shown remarkable skill and ingenuity in devising their apparatus.

Dr. W. H. Hatfield (Sheffield) expressed his great pleasure in listening to a paper read by Professor Benedicks, to whom members were much indebted for the researches which he had published from time to time on physical constants of a similar nature to those described in the present paper. He did not think it was necessary to be anxious because there were discrepancies. Speaking generally, when discrepancies were disclosed in the course of a very careful investigation it meant that something of consequence was going to be discovered.

With reference to Sample *B*, in regard to which the difference was greatest, he did not think for a minute that heterogeneity in the steel, as suggested, was the explanation, but that purely physical causes would be found to be responsible for the variation.

With regard to the figure given for thermal conductivity, 0·187, it was very necessary that it should be known exactly what the figure was, because, as Dr. Desch had pointed out, it was of great practical importance. It seemed to him that the figure which the authors gave was high. No doubt they were aware that Ingersoll and his co-workers stated the figure to be 0·1428, and Jaeger and Diesselhorst gave 0·151 and 0·143. Those two figures were in close agreement, and it was for the investigators who were attacking the physical constants in the special way the authors were doing to come to agreement.

Dr. Arthur Bramley (Loughborough) said he desired to ask two questions on the very interesting paper that had been presented.

He presumed that in regard to the spherical method, in which the sphere was turned and then cut in two, that the plane section bore some definite relationship to the direction of rolling. He would like to ask whether a sphere had been made in which the plane section was transverse to the direction of rolling and another one at right angles—*i.e.* parallel to the direction of rolling. If that were the case, did the ellipse, or the irregularity of the figure showing the difference in the conductivity, depend upon it? A good many years ago Professor Callendar carried out a number of experiments on a continuous flow method of determining conductivity with cylindrical tubes, which worked exceedingly well for materials of low conductivity, but he found its use for materials of high thermal conductivity very difficult indeed.

Mr. E. H. Saniter (Member of Council) thought that if the authors had used spheres made from castings instead of from rolled material they might have overcome the difficulty which had just been referred to.

Professor Benedicks, in reply, expressed his deep gratitude for the extremely kind remarks that had been made. He wished to point out to Dr. Desch that the character of the phenomena referred to was extremely capricious. On repeating the experiments under exactly the same conditions, very nearly the same result might be obtained. On the other hand, there were very considerable changes. For instance, the figures given in the paper showed that in a given case, on low heating, the temperature difference was larger on the left-hand side, and on heating more it was larger on the right-hand side. The material examined was used in the actual construction of boilers. The trouble was to get a determination which would be reliable, and the authors found that it was not possible to get it from spherical specimens; as pointed out by Dr. Desch, the resulting conductivity was larger than that which would be calculated according to the ordinary values. Dr. Desch also asked a question concerning the possibility of obtaining direct evidence of temperature differences in an ordinary plate; the authors had made experiments in that direction, but they were at present only in the early stages.

With regard to Dr. Hatfield's remarks, he desired to say that the elimination of errors had proved very difficult indeed. The authors did not claim that their figure for iron was the true one; they only believed it to be correct because they had done everything possible to get a reliable result. It was impossible to make a more definite statement on account of the great difficulties.

Dr. Bramley had asked if spheres had been prepared in a direction parallel with, and at right angles to, the axis. That had been done. The authors had expected to obtain a very regular result, with the same temperature difference, when the plane of the hemisphere was at right angles to the axis of the cylinder. When they first made that determination it was found that the deviation from left to right was as 2·2 to 1, so that there was a considerable difference in that case, and they did not pursue their investigations on the other pair of hemispheres because the difference would probably have been still larger.

ELECTROCHEMICAL POTENTIALS OF CARBON AND CHROMIUM STEELS.*

By CARL BENEDICKS and ROBERT SUNDBERG
(Metallografiska Institutet, Stockholm).

Introduction.

At a very early date the corrosion of iron was investigated by Swedish chemists. It was established by Bergman (1773),[1] soon after his discovery of "aëric acid" as being carbon dioxide (in our language), that "water which is saturated with aëric acid corrodes and dissolves metallic iron." This constitutes the starting-point of the "carbonic acid theory."

Rinman,[2] in his "Essay on the History of Iron" (1782), tells us that dry air does not corrode iron, but moisture-laden air does. The rust "must be formed by some kind of acid, which in the presence of moisture will exert a dissolving, attacking, or corroding influence on the iron" (p. 741). The red-short iron is mentioned as having a greater tendency to rust than other iron (p. 49). Rinman carried out some elucidating experiments on pig-iron from Hällefors, in the form of drillings, and found, according to the air theory of Scheele, that the "good air," *i.e.* the oxygen, after the lapse of a month, had been absorbed by the rusting drillings (p. 743).

Rinman,[3] in his "Mining Dictionary," also notes that "the other less noble metals seem likewise to be partially corroded by moist air."

At about this time the English chemist Austin (1788) observed that an originally neutral water tends to become alkaline during the corrosion process, as pointed out by U. R. Evans in his excellent work, "The Corrosion of Metals" (London, 1924), to which we may refer for further historical details.

As reported there, De la Rive, in 1830, was the first to consider the corrosive action on metals as being an electrochemical process.

Another investigation at approximately the same period, which should not be forgotten, is that of von Bonsdorff,[4] "On

* Received June 22, 1926.

the Influence of the Atmospheric Air on the Oxidation of Metals." He proved convincingly that the rusting of iron, which easily takes place in moist air, does not occur if water cannot be deposited on the surface of the iron.

This fact was important for the electrochemical theory. Referring to this observation, De la Rive writes as follows: ". . . this fact, which I think is well established, proves that the oxidation of a metal in the air is not merely the result of a direct combination; actually, a more complicated phenomenon takes place, *i.e.* a voltaic action, the metal decomposing the water on account of a local voltaic action, which is aided by the presence of dissolved oxygen acting on the hydrogen formed (*de cette eau*); the presence of carbonic acid facilitates the action, inasmuch as it renders the water better conducting." (5) We think this statement merits quotation here, as it anticipates much of our present knowledge.

The first scientist to take up experimentally the electrochemical theory of de la Rive was the Swedish physicist, Ericsson-Aurén (1897).(6) In collaboration with him, Palmær (1901) (7) examined the corrosion of metals in the light of the Nernst theory. Somewhat later Palmær (1903) (8) pointed out the following: "If, in the acid solution, a depolariser for hydrogen is present, *i.e.* a substance which may successively oxidise the hydrogen formed, it is evident that the counter e.m.f. of the local element diminishes, and the dissolution of the metal is facilitated. Direct evidence of this was supplied by Weeren (1891), who, however, interpreted the phenomenon in another way."

Somewhat later Whitney, Cushman, Walker, Tilden, Aston (1916), Evans, and others, carried out work which is now universally recognised as being of practical importance and fruitful of results.

For this newer development, which is mainly characterised by a clearer understanding of the part played by oxygen, there are apparently, from a quantitative point of view, two lines in particular along which accurate measurements are desirable. In the first place, the electrochemical potential, the most direct expression of the electrolytic solution tendency of a metal, must be ascertained in an accurate way; the anodic behaviour of a metal is thus determined. On the other hand, in order to gain

knowledge of the cathodic behaviour of a metal, it is necessary to possess an accurate knowledge of the rather obscure phenomenon known as overvoltage, the variations in which may fundamentally influence the action of a local element.

The aim of the present paper is exclusively that of giving some trustworthy data concerning the electrochemical, or electrolytic, potentials. In this connection the clear understanding of the influence of oxygen, resulting from the above recent work, inspires investigation along two parallel lines :

I. The potential of a metal in a solution which is entirely devoid of free oxygen ;

II. The potential of a metal in a solution containing oxygen.

In other words, the programme for the present research is the determination of the potential in an aqueous solution—(1) in presence of free hydrogen, (2) in presence of free oxygen.

So far as present knowledge goes, the electrolytic tension of a metal, say iron, must be referred to a given liquid, say water, written as H — OH, and the potential then obtained must be due to a compromise, or to an equilibrium, either between iron and Fe ions on the one side and hydrogen and H ions on the other, or between iron and Fe ions on the one side and some oxygen compound and OH ions on the other.

Probably both cases are equally important. For the sake of convenience, it is proposed to use the expression *H-Potential*, E_H, for case 1, and *O-Potential*, E_O, for case 2.

In order to arrive at satisfactory results in the first case, the previous work of Richards and Behr, jun.,[9] and also that of Foerster,[10] has been of great service ; the essential improvement made in the present work involves only a more practical way of preparing the oxygen-free and strictly neutral solution used.

For the second case, it was necessary to discover some practicable way of obtaining reproducible results in the presence of oxygen.

The determinations were carried out on two series of carbon steels, and also on a series of "stainless" steels, which are especially interesting from an electrochemical point of view.

This short introduction should not be concluded without mentioning the potential determinations on carbon steels executed

by Heyn and Bauer [11] which, though hardly satisfying modern requirements, were excellent for the time.

A few determinations of the potential of some stainless steels were published by Tammann and Sotter,[12] and by Strauss [13]; these will be considered later, together with a few other data referred to by Kremann.[14]

Experimental Details.

Preparation of a Solution devoid of Free Oxygen.—As already acknowledged, our work has been considerably facilitated by the previous work of Richards and Behr, jun.,[9] who first correctly determined the electrochemical potential of iron, and also by the investigation of Foerster,[10] who confirmed their results.

In the previously rather tedious method of preparation of a sufficient quantity of the oxygen-free solution of ferrous sulphate, an improved procedure was introduced, permitting of more rapid work without impairing its quality. The solution was prepared by dissolving crystallised ferrous sulphate (*Kahlbaum*) in distilled water which had been freed from air by boiling. Some sulphuric acid and filings of electrolytic iron were then added in order to reduce any ferric ions present. This reduction, however, being very slow on account of the low speed of diffusion, a stirrer provided with a mercury lock was introduced in the form of an iron propeller, the blades of which could be folded so as to permit its introduction into a large bottle. When rotating the propeller blades rose to the horizontal plane, thus producing an effective stirring. However, a very long time—several months, according to Richards —is needed to get rid of the last trace of acid, this being consumed only by the iron filings. This trouble was overcome by the addition of barium hydroxide to the solution after its complete reduction (absence of ferric ions proved by means of the sulpho-cyanide reaction). As a matter of fact, the addition of barium hydrate produces strict neutrality, and the excess barium hydrate and the barium sulphate quickly sink to the bottom. Naturally the strict neutrality of the solution is indispensable, as otherwise free hydrogen as well as hydrogen ions will be present—which does not correspond to the desired equilibrium.

The solution was prepared and kept in an atmosphere of hydrogen, which had been washed with an alkaline pyrogallic solution, and passed through a tube containing glass fibre.

Apparatus Used.—In order to permit of carrying out a number of determinations simultaneously, a glass vessel was used as shown in Fig. 1. A glass cylinder A (height, 70 millimetres;

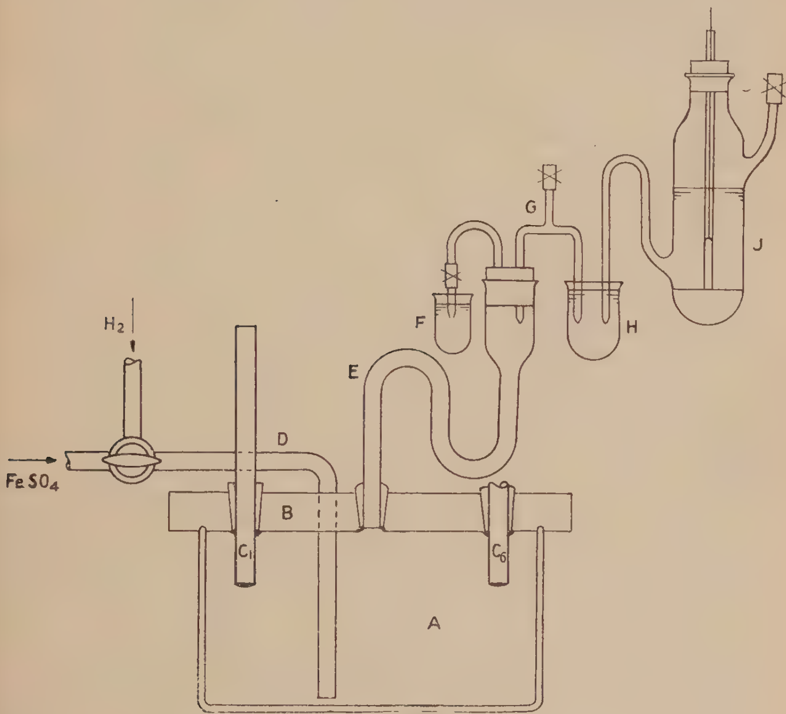

FIG. 1.—Apparatus for Potential Determinations.

diameter, 135 millimetres) was provided with a hard rubber cover, B, carefully ground on to the upper edge of the cylinder. In B ten holes (10 millimetres in diameter) were drilled in a circle. In these the cylindrical specimens (diameter, 8 millimetres) $C_1 \ldots C_6 \ldots C_{10}$ were fixed by means of short rubber tubings. The cylinders projected 20 millimetres below the cover. A thin coating of Chatterton compound was used, so as to avoid any contact between the liquid and the rubber, the presence of which

in the solution was found to influence the potential values. The plane surfaces of the specimens were also covered by a layer of Chatterton compound. The specimens C having been mounted in this way, hydrogen was supplied through the tube D; the hydrogen escaped through the tube E provided with a water-trap F. After about twenty minutes the hydrogen supply was replaced by the ferrous sulphate solution. This entirely filled A and mounted into E. By means of an inverted U-tube G, which could be filled with 1–*N* potassium chloride solution, E communicated with a vessel, H, filled with 1–*N* potassium chloride solution, into which the free end of the calomel electrode J dipped.

This was a 1–*N* potassium chloride electrode, prepared according to the prescription of Ostwald-Luther.* From time to time it was checked against a similar one, used only for comparison.

The potential measurements were made according to the Poggendorff compensating method, using a sensitive moving-coil galvanometer (1 millimetre at 1 metre distance = $3 \cdot 8 \times 10^{-7}$ volt) as zero instrument. A resistance of 10,000 ohms being used in series, no polarising influence was traced from the adjusting of the contact. The readings are accurate to $\pm 0 \cdot 5$ millivolt.

The procedure for obtaining the O-potentials will be described later.

Steels Used—Analyses—Electrical Resistance.—The carbon steel material was that used previously by Benedicks,[15] comprising steels prepared in the Kjellin induction furnace at Gysinge, and some open-hearth steels from Fagersta. To these were added a remarkably pure "Swedish Armco" iron from Domnarfvet (marked 0), and a number of stainless steels. The latter were kindly presented by the Avesta Jernverks A.B., and from them 8-millimetre cylinders were turned. The specimens as a rule were in the primary forged state, annealed state, and hardened state.

The stainless steels were tested in the primary condition as rolled; and again after a normalising annealing during fifteen minutes at a temperature of 780° C., followed by air cooling, and also in the hardened state, obtained by heating for fifteen minutes at 975° C., and subsequently quenching in water at room temperature.

In order to characterise the stainless specimens investigated,

* "Physico-chemische Messungen" Fourth edition. Leipzig, 1925.

TABLE I.—*Analyses of Carbon Steels from Gysinge and Fagersta.*

Element.	Gysinge Steels.									Fagersta Steels.					
	0.	1.	2.	3.	4.	5.	6.	7.	8.	A.	B.	C.	D.	E.	F.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
C	0·02	0·08	0·45	0·55	0·90	1·20	1·35	1·50	1·70	0·16	0·38	0·23	0·33	0·62	0·95
Si	...	0·03	0·65	0·86	0·28	0·30	0·26	0·12	0·08	0·009	0·079	0·019	0·047	0·308	0·303
Mn	0·04	0·13	0·35	0·44	0·41	0·44	0·54	0·29	0·29	0·32	0·42	0·43	0·41	0·45	0·45
P	trace	0·009	0·015	0·014	0·014	0·014	0·014	0·013	0·013		0·024 to 0·028				
S	0·005	0·005	0·02	0·02	0·015	0·01	0·015	0·02	0·03	0·012	0·012	0·012	0·012	0·012	0·012

TABLE II.—*Analyses of Stainless Steels.*

Element.	1. 1000Y	2. 801	3. 831	4. 711	5. 715	6. 1065 – 3	7. 1065 – 2	8. 1065 – 1	9. 1065 – 4	10. 720
	%	%	%	%	%	%	%	%	%	%
C	0·20	0·04	0·08	0·05	0·07	0·45	0·34	0·28	0·47	0·07
Si	0·15	0·23	1·06	0·43	0·36	0·05	0·05	0·07	0·04	0·57
Mn	0·31	0·12	0·14	0·26	0·51	0·24	0·24	0·26	0·22	0·50
Cr	13·05	8·05	23·20	13·05	14·80	12·65	12·80	12·70	12·75	13·80
Ni	...	...	...	...	...	0·4	0·4	0·4	0·4	...

The percentages of phosphorus and sulphur were about 0·025 to 0·030.

their specific gravity and electrical resistivity were determined by means of a pycnometer filled with water and the Thomson bridge respectively. The specific gravity values are given in Table III.A, and the resistivity values in Table III.B. The resistivity and other properties of the carbon steel specimens are given in the thesis previously referred to.(15)

TABLE III.A.—*Specific Volume and Specific Gravity of the Stainless Steels.*

1. *Specific Volume in Cubic Centimetres at + 16° C.*

Mark.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
As rolled .	0·12936	0·12860	0·13119	0·12946	0·12965	0·12935	0·12941	0·12924	0·12940	0·12963
Normalised .	0·12934	0·12863	0·13118	0·12946	0·12964	0·12937	0·12955	0·12924	0·12935	0·12965
Hardened .	0·12997	0·12862	0·13120	0·12955	0·12971	0·13019	0·13046	0·12998	0·13007	0·12978

2. *Specific Gravity (Grammes per Cubic Centimetre) at + 16° C.*

Mark.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
As rolled .	7·728	7·776	7·622	7·722	7·710	7·728	7·728	7·740	7·728	7·716
Normalised .	7·737	7·776	7·622	7·722	7·716	7·728	7·716	7·740	7·728	7·710
Hardened .	7·692	7·776	7·622	7·716	7·710	7·680	7·663	7·692	7·686	7·704

TABLE III.B.—*Electrical Resistivity of the Stainless Steels.*

In Microhms per Centimetre at + 20° C.

Mark.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
As rolled . . .	50·7	45·0	73·2	58·2	57·9	47·3	47·9	48·8	47·4	62·7
Normalised . .	51·1	45·0	73·7	57·1	56·1	48·0	50·4	49·5	47·2	60·5
Hardened . . .	62·8	46·3	74·8	60·1	60·0	65·1	63·1	65·5	63·5	64·4

STUDY OF SOME INFLUENCING FACTORS.

"*Reproducibility.*"—When using the final experimental arrangement the ability to reproduce the determinations proved to be rather satisfactory. As an example Table IV. is quoted, containing the values obtained on the same two specimens of Fagersta steel marked *A*, which were introduced in each series in order to check the accuracy of the results; they were in the annealed and the quenched state, respectively.

TABLE IV.—*Potentials Measured against a 1–N Calomel Electrode.*

Date.	Fagersta Steel *A*.	
	Annealed.	Hardened.
	Volt.	Volt.
March 28, 1926	– 0·712	– 0·710
,, 31, ,,	...	– 0·7045
April 9, ,,	– 0·706	– 0·704
,, 13, ,,	– 0·7075	– 0·703
,, 15, ,,	– 0·709	– 0·7045

It will be seen from the table that, apart from the two values obtained at the outset, there is very good agreement between the observed values.

In the determinations on stainless specimens, a definite specimen was used for checking purposes. In this case a certain variation did occur; this, however, was found to be due to some action of light, which will be dealt with below. The figures obtained may as a rule be considered as correct within a few millivolts.

For other figures regarding "reproducibility," see Tables V. and VI.

Influence of Size of Exposed Surface.—In order to ascertain if the absolute size of the surface of the specimen had any influence on the results, some comparative tests were made on two different steels. Of each steel, three cylinders were tested: one was covered with Chatterton compound, except on the plane end surface; the other two were both covered on the plane surface, but were left exposed for a length of 10 millimetres and 30 millimetres respectively.

The potential registrations continued during forty hours, and showed no characteristic difference, the deviations in no case amounting to more than ± 3 millivolts. Notwithstanding this, as already stated, a constant free cylinder length of 20 millimetres was used throughout.

Influence of the Grade of the Grinding Paper.—For the investigation of the possible influence of the condition of the surface, three specimens of the same Fagersta steels *A* and *B* were chosen. They were ground with Hubert emery-paper Nos. 1, 00, and 0000, respectively. A length of 1 centimetre of the cylinders was then exposed to the ferrous sulphate solution. No serious difference could be traced in the final values, so that the grade of the paper used may be immaterial. It was found, however, that the time necessary to reach the final equilibrium was rather shorter for No. 1 than for the others. No. 1, as well as 00, is decidedly preferable in comparison with 0000, apart from the question of the greater labour involved in the use of 0000, on account of the fact that the primary value obtained with 0000 is considerably lower than with the others. This is probably due to a higher amount of oxygen being bound to the surface in that case.

Influence of Hydrogen in the Ionic and in the Gaseous State.—As already pointed out here, and previously by Foerster,[(10)] the equilibrium potential of iron in an oxygen-free aqueous solution must depend on the potential of hydrogen as well as on that of the iron itself. If this view is correct, the addition of free hydrogen to the surface of the iron should render the potential value more negative.* This was actually found to be the case for

* In the graphs of the present work the negative, "base," potentials correspond to the upper part of the diagrams, the positive, "nobler," potentials to the lower parts, in harmony with the system of notation frequently used. Consequently a raised or increased potential value signifies that this has become more negative; a lower potential is a more positive one.

an iron with only 0·02 per cent. carbon. When equilibrium had been attained in the oxygen-free solution, which likewise contained no visible free hydrogen, a slow current of pure hydrogen was introduced near the specimens. Its potential then rose from − 0·706 to − 0·713 volt (referred to 1–*N* calomel electrode).

Similarly, the potential in some cases was found to be higher than might be expected, due to the adhesion of hydrogen in the gaseous state to the surface of the specimen, and it was found to be essential for obtaining correct values that the surfaces should be entirely freed from hydrogen bubbles.

On the other hand, an increase in the concentration of the hydrogen ions must lower the hydrogen potential. This was likewise found to be the case; an equilibrium potential of − 0·71 volt being observed on the same iron as before, a small addition of sulphuric acid, which had been freed from air, caused the potential value to fall to about − 0·59 volt.

Finally, unless the surface of the specimen has been saturated with hydrogen the potential will be too low, even in a strictly neutral solution.

This was verified by replacing the hydrogen, used for removing the air before admission of the liquid, by nitrogen, which had been carefully purified from oxygen by means of an alkaline pyrogallic solution. In this case a potential of − 0·698 and − 0·702 volt was obtained, instead of − 0·712 as found under normal conditions. These observations are in agreement with theory.

Influence of Light.—As will be explained later, it was discovered only in the later stages of the investigation that daylight exerts some influence on the potential values obtained, and no special precautions were taken to preserve a constant illumination or complete darkness. In continuing the work this will be desirable, as is shown in the latter part of this paper.

Method of Determining O-Potentials.—In order to arrive at a satisfactory determination of the O-potentials—which was one of the chief objects of the present work—the direct supply of air to the oxygen-free solution was first tested to determine the change produced thereby.

The air, which had been purified of carbon dioxide, was blown through a capillary sealed to the bottom of a test-tube

containing the solution. The final result obtained is shown in Fig. 2A, representing one of the series made on Fagersta carbon steel *A*.

At A (see Fig. 2A) the air current was turned on. The potential being in this case subject to slight changes, a maximum and a minimum value was read in each case.

It will be noted that under a constant air supply (corresponding to 45 to 50 bubbles per minute in a wash-bottle) a fairly constant value, $-0 \cdot 636$ volt, was obtained after seven or eight hours. After another four hours, during which this value remained con-

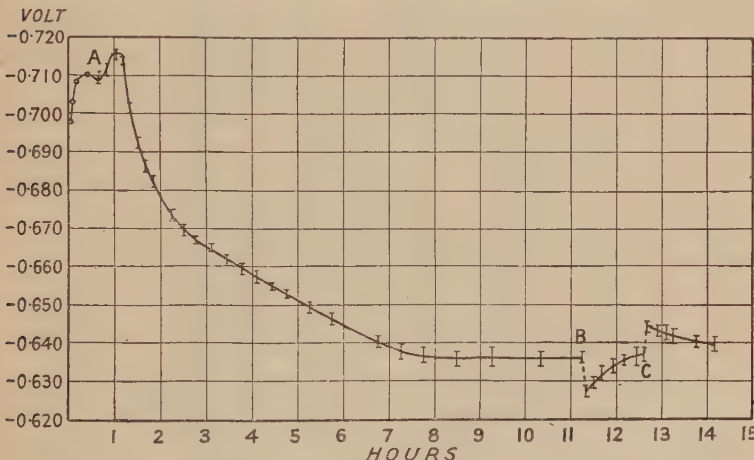

FIG. 2A.—O-Potential of a Carbon Steel (*A*) in an $0 \cdot 82$–*N* $FeSO_4$ solution against a 1–*N* calomel electrode. Oxygen supplied by air current.

stant, the speed of the air current was (at B) increased up to 220 to 240 bubbles, causing at first a decided lowering of the potential; after $1\frac{1}{2}$ hours, however, the potential returned to its previous value. Later (at C), a change of the air speed to 52 to 53 bubbles per minute caused a rise in the potential, but after $1\frac{1}{2}$ hours it practically regained its original value.

Hence, the value of $-0 \cdot 636$ volt seemed to correspond to some state of equilibrium, which however was reached but slowly when atmospheric air was blown through.

The addition of a definite amount of an oxidising reagent more effective than gaseous oxygen was then tried, care being taken not to introduce any foreign ions which would remain in the solution.

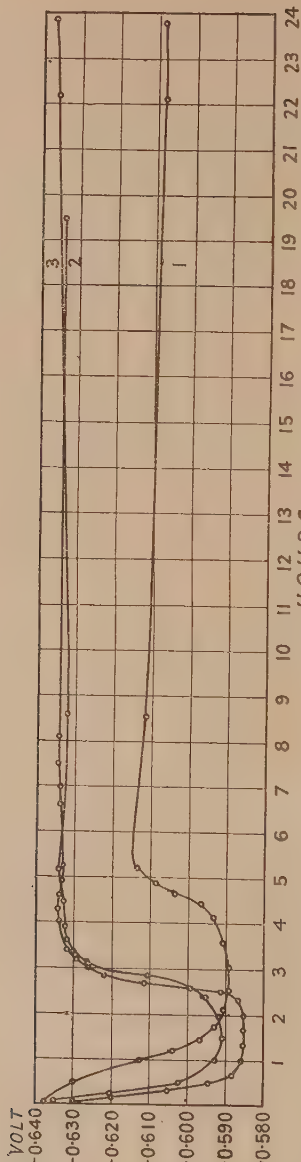

FIG. 2B.—O-Potential of a Carbon Steel (A) in an 0·82–N $FeSO_4$ solution against a 1–N calomel electrode. Oxygen supplied by adding different quantities of H_2O_2; (1) 5 cubic centimetres; (2) 12·5 cubic centimetres; (3) 25 cubic centimetres.

A solution of hydrogen peroxide, as proposed by Sederholm, was found to answer the purpose, if added in a quantity beyond a definite limit. This is illustrated by the three curves in Fig. 2B, corresponding with an observation series obtained by the addition of a 3 per cent. hydrogen peroxide solution in the following quantities: (1) 5 cubic centimetres, (2) 12·5 cubic centimetres, and (3) 25 cubic centimetres per 100 cubic centimetres of ferrous sulphate solution.

Immediately after the addition of the peroxide, which gave a dark red colour, the potential was found to decrease to a value between $-0·63$ and $-0·64$ volt, and it soon continued to decrease rather quickly down to about $-0·59$ volt, which corresponds with a precipitation occurring in the solution. After this, however, the potential rose again.

In the case of the 12·5 and 25 cubic centimetres solutions a constant value was reached after about four hours; for the 5 cubic centimetres solution the general behaviour was similar, but the final value was much lower. Consequently, in order to obtain a constant value, a peroxide addition higher than 5 cubic centimetres was necessary. The constant value obtained, using the solution of 12·5 cubic centimetres or more, was found to be $-0·634$ volt, or practically identical with the equilibrium value already obtained by means of an air current ($-0·636$ volt).

In the same way a stainless steel plate (0·10 per cent. carbon, 13 per cent. chromium) was treated. Fig. 3, curve 1, shows the effect of an air current being turned on (at A); the curve is certainly a very regular one, and it seems to give an asymptotic value, below $+0·26$ volt, but even after the lapse of forty-four hours this value had not been reached. Curve 2 illustrates the influence of the addition of 12·5 cubic centimetres of 3 per cent. hydrogen peroxide to 100 cubic centimetres of solution (being added at point B). Within half an hour the potential dropped from the original value, $-0·635$ volt (a comparatively low value, due to some previous passivity, as seen from the initial parts of the curves), to $+0·28$ volt, and reached, after at least ten hours, a practically constant value of about $+0·301$ volt. This value, of course, does not coincide with that previously obtained with an air current. The latter, however, not being a final one, the difference is not very considerable, especially when

compared with the great total difference in potential, due to the oxidation.

On account of these results, the addition of hydrogen peroxide

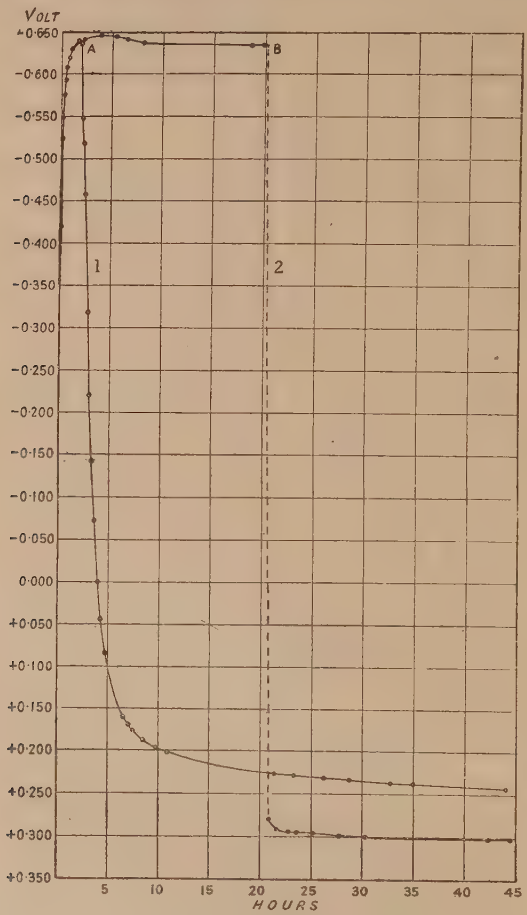

FIG. 3.—O-Potential of a Stainless Steel in an $0{\cdot}82$–N solution of $FeSO_4$ against a 1–N calomel electrode.

(1) Oxygen supplied by means of air,
(2) Oxygen supplied by adding H_2O_2.

was adopted in the following work as being a practical and time-saving way of obtaining accurate potential values characteristic of the presence of oxygen, and designated here as O-potentials (E_0).

The peroxide addition used was 12·5 cubic centimetres of 3 per cent. H_2O_2 per 100 cubic centimetres of the solution. The normality of the ferrous sulphate solution was not quite 1, but 0·82–*N*. The correction to apply for obtaining values corresponding with a 1–*N* ferrous sulphate solution amounts to + 0·0028 volt.

Experimental Results from Carbon Steel.

As an example of the H-potential-time curves directly obtained, the record of the specimens of Fagersta steel, which were quenched at 1200° C., is reproduced in Fig. 4. This is rather noteworthy, first on account of the regularity generally obtained, and, secondly, for the interesting fact that the *initial* sequence of the different steels generally is the same as the final one, though showing a greater dispersion. This might suggest the question as to whether these initial values may not be preferable for the characterisation of the different steels; nevertheless, accidental circumstances may have an undesired influence on the initial values.

As an example of the O-potential-time curves obtained, those for the annealed Gysinge steels are given in Fig. 5.

The final values of E_{H} and E_{O}, as read after the lapse of twenty-two or twenty-four hours, are compiled in Table V. They all refer to a temperature of + 16 ± 2° C. and to the 1–*N* calomel electrode (E_c). In order to obtain the corresponding values in the hydrogen scale (E_h), use must be made of the formula:

$$E_h = E_c + 0\cdot 286 \text{ volt.}$$

The figures given in Table V. are graphically reproduced in Figs. 6, 7, and 8.

Before entering upon a discussion of the figures obtained, it may be remarked that the specimens which had been immersed in the oxygen-free solution were entirely uncorroded. On the other hand, after the addition of hydrogen peroxide the exposed surfaces were visibly corroded; thereby the hardened specimen showed fairly large characteristic curled stains, while in the unquenched specimens the corroded spots were much more localised.

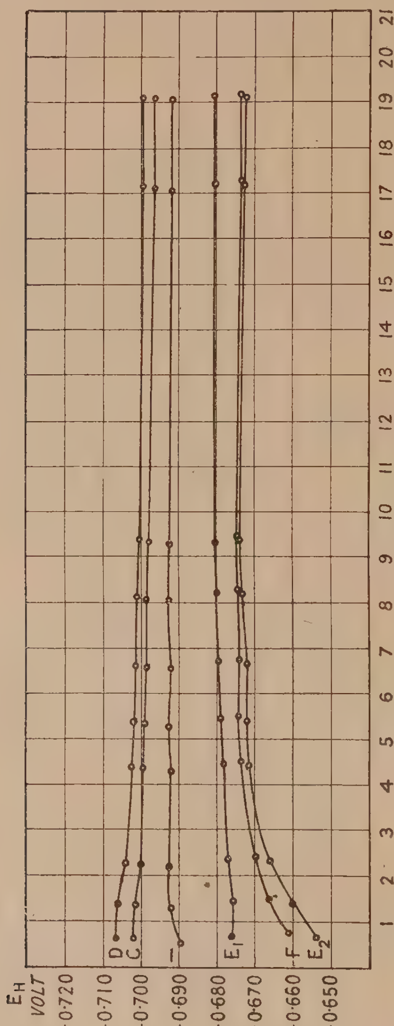

FIG. 4.—H-Potential Time Curves for Fagersta Carbon Steels, Quenched at 1200° C. 0·82–N $FeSO_4$ solution carefully purified from free oxygen. Potential measured against a 1–N calomel electrode.

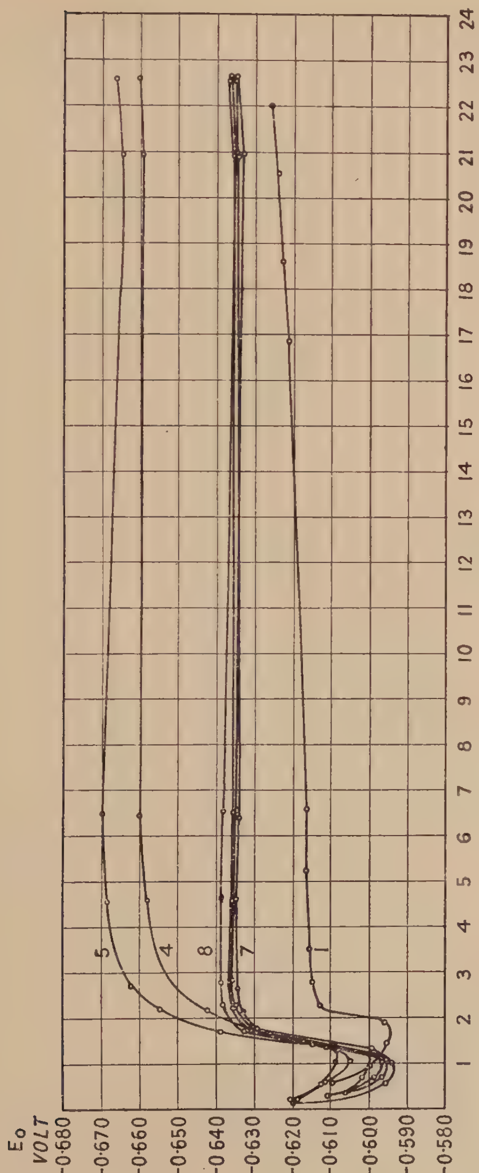

FIG. 5.—O-Potential Time Curves for Annealed Gysinge Carbon Steels. Solution: $0 \cdot 82$-N $FeSO_4$, to which H_2O_2 was added. Potential measured against a 1-N calomel electrode.

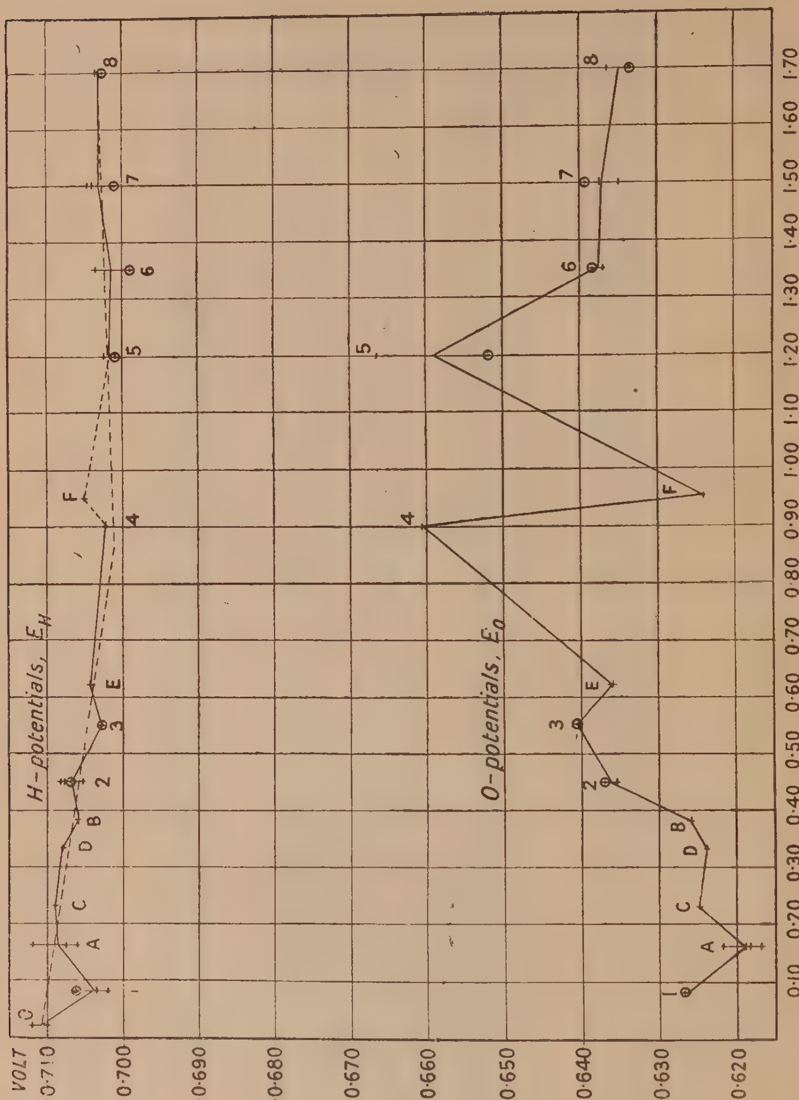

FIG. 6.—H- and O-Potentials of Unquenched Carbon Steels.

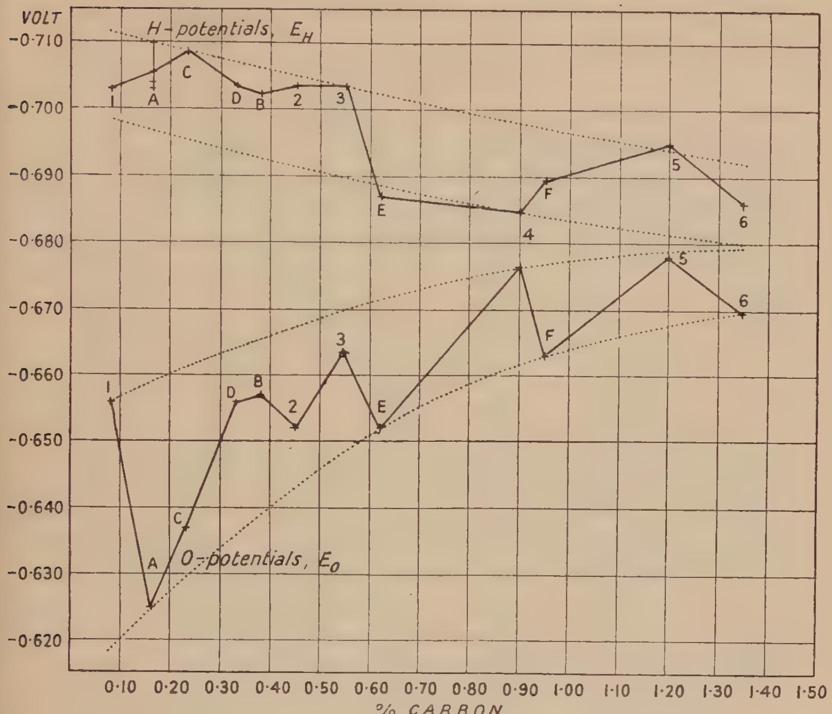

FIG. 7.—H- and O-Potentials of Carbon Steels Quenched at 800° to 850° C.

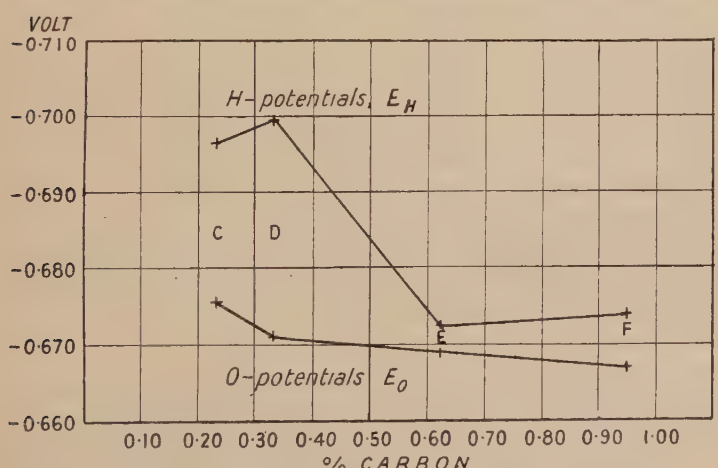

FIG. 8.—H- and O-Potentials of Carbon Steels Quenched at 1200° C.

TABLE V.—*Potentials of Carbon Steels in 0·82–N $FeSO_4$, Measured against a 1–N Calomel Electrode.*

	Mark.	0.	1.	A.	C.	D.	B.	2.	3.	E.	4.	F.	5.	6.	7.	8.
	Carbon per cent.	0·02	0·08	0·16	0·23	0·33	0·38	0·45	0·55	0·62	0·90	0·95	1·20	1·35	1·50	1·70
		Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.
H-Potential, E_H.	As forged	−0·712 −0·710	−0·707	...	...	...	...	−0·707	−0·703	...	...	...	−0·701	−0·699	−0·701	−0·703
	Annealed	...	−0·704 −0·702	−0·712 −0·706 −0·7075 −0·709	... ... −0·709	... ... −0·708	... ... −0·706	−0·705 −0·708 −0·708 ...	...	−0·704	−0·702	−0·705	−0·703	−0·704	−0·704 −0·705	−0·704
	Quenched at 800° to 850° C.	...	−0·703	−0·710 −0·7045 −0·704 −0·703 −0·7045	−0·709	−0·704	−0·703	−0·704	−0·704	−0·687	−0·685	−0·690	−0·695	−0·686	...	...
	Quenched at 1200° C.	...	...	...	−0·697	−0·700	...	...	...	−0·673	...	−0·674	...	...	...	...
O-Potential, E_O.	As forged	...	−0·627	...	...	...	...	−0·637	−0·641	...	...	...	−0·652	−0·639	−0·640	−0·634
	Annealed	...	−0·627	−0·622 −0·619 −0·617 −0·619	−0·625	−0·624	−0·626	−0·637 −0·636	...	−0·636	−0·661	−0·624	−0·667	−0·637	−0·635 −0·638	−0·637
	Quenched at 800° to 850° C.	...	−0·656	−0·625	−0·637	−0·656	−0·657	−0·652	−0·664	−0·652	−0·677	−0·663	−0·678	−0·670	...	...
	Quenched at 1200° C.	...	...	...	−0·676	−0·671	...	...	...	−0·669	...	−0·667	...	...	...	...

Discussion of the Results from Carbon Steels.

Unquenched Specimens.

H-Potentials, E_H.—As seen from Fig. 6, there is very little difference between the annealed specimens (given as dashes) and the specimens as forged (circled dots), so that only the average figures need be considered. The diagram shows that the *H-potential decreases slightly with increasing carbon content, up to $C = 0 \cdot 90$* per cent.

For the purest iron tested ($C = 0 \cdot 02$ per cent.), the H-potential value * found in $0 \cdot 82$–N $FeSO_4$ solution is $E_H = -0 \cdot 711$ volt, or, reduced to 1–N $FeSO_4$ solution, $E_H = -0 \cdot 711 + 0 \cdot 003 = -0 \cdot 708$ volt.

This value stands in very good harmony with the figure found by Richards and Behr [9] for pure compact iron melted *in vacuo*, viz. $-0 \cdot 761$ against a $0 \cdot 1$–N calomel electrode, or for a 1–N calomel electrode as used here, $E_H = -0 \cdot 761 + 0 \cdot 051 = -0 \cdot 710$ volt. The figures found by Foerster [10] came very near those of Richards and Behr.

This value for pure iron decreases with increasing carbon content in the ratio of about $0 \cdot 010$ volt per 1 per cent. of carbon, so that the relation between E_H and carbon content C (in weight per cent.) may be expressed by the formula :

$$E_H = -0 \cdot 708 + 0 \cdot 010C \text{ volt, which is valid for } C \leqq 0 \cdot 9 \text{ per cent.}$$

For carbon contents greater than $0 \cdot 9$ per cent. there seems to be a slight increase ; the present determinations, however, do not permit of giving any definite figure.

In spite of the fact that the steels are of quite a different origin, their potentials change in a rather regular way. There are only two clear exceptions, No. 1, and F. As for No. 1, it seems quite probable that the low value found is due to a certain oxide content, the metal being a welded Walloon iron ; the iron-oxide slag occurring in it will of course give a lower potential value.

As for F, which deviates slightly towards higher values,

* The potentials, being referred to the calomel electrode, might have been designated as E_c, and consequently as E_{cH} and E_{cO} respectively ; the c has, however, been left out.

its phosphorus content, slightly higher than that of No. 4, scarcely seems sufficient to explain this deviation. In any case, the changes in E_H seem to correspond with the curves of the equilibrium diagram.

O-Potentials, E_0.—Between the annealed specimens and the specimens as forged no sensible difference occurs (Fig. 6), as was also the case for E_H (No. 5, however, is an exception). E_0 is in every case found to be considerably "nobler" than E_H. An evident increase in E_0 takes place with increasing carbon content, up to 0·9 per cent. Beyond 1·2 per cent. there is a considerable decrease in E_0.

A prominent irregularity is the very low value of F, of which the analysis scarcely gives any explanation, but it might be supposed to be related to a higher oxygen content in F (open-hearth) than in No. 4 (electric steel).

Taken as a whole, the E_0 values likewise are found to stand in a definite relation to the equilibrium diagram.

As a rule, the E_0 values are "antibate"—that is, are influenced in an opposite way—to the E_H ones.

Quenched Specimens.

H-Potentials, E_H.—The quenching is found throughout to cause a "nobler" E_H than that of the unquenched specimens. This is evident from the curves in Fig. 7 for the steels quenched at 800° to 850° C. The effect is considerably increased by an increased quenching temperature, as seen in Fig. 8, giving graphs for steels hardened at about 1200° C.

E_H decreases, though in an irregular way, with increasing carbon content; roughly, 1 per cent. hardening carbon seems to lower E_H about 0·020 volt.

O-Potentials, E_0.—Quenching throughout raises the E_0 values to a considerable degree (Fig. 7). With increasing carbon content the E_0 rises at first quicker, and then at a slower rate, as indicated by the dotted limiting curves in Fig. 7.

This effect increases considerably with increasing quenching temperature, as evidenced by Fig. 8. E_H and E_0 seem to depend on the quenching temperature still more than the electric resistivity (possibly due to the direct influence of γ-iron). As

seen in Fig. 8, the effect of quenching at a high temperature is to *bring* E_H *and* E_O *rather close together.*

The purport of this rather unexpected fact will be that a *differential aeration*, which otherwise strongly affects corrosion (Aston, Evans), *will exert very little influence on the corrosion of a hardened object made of high-carbon steel.* This seems to afford a plausible explanation of the remarkable resistance against rusting which is exhibited by, say, a razor blade.

As in earlier work on carbon steels no discrimination was made between E_H and E_O, no previous figures [14] lend themselves to a comparison with those obtained in the present investigation.

Experimental Results from Stainless Steel.

As examples of the E_H-time curves obtained, the record of Nos. 1–5 in a normalised condition is reproduced in Fig. 9 ; the corresponding E_O-time curves are reproduced in Fig. 10.

The final values of E_H and E_O, as obtained after about twenty-four hours, are compiled in Table VI. Here the figures designated as " corrected values " are obtained not from the final readings, as was done in the other cases, but from readings where no sensible light influence was to be feared.

Table VI.—*Potentials of Stainless Steels in* $0 \cdot 82$–*N* $FeSO_4$, *Measured against a* 1–*N Calomel Electrode.*

	Mark.	2.	8.	7.	6.	9.	4.	1.	10.	5.	3.
	Carbon per cent.	0·04	0·28	0·34	0·45	0·47	0·05	0·20	0·07	0·07	0·08
	Chromium per cent.	8·05	12·70	12·80	12·65	12·75	13·05	13·05	13·80	14·80	23·20
H-Potentials, E_H.		Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.	Volt.
	As rolled .	− 0·735	− 0·687	− 0·661	− 0·702	− 0·708	− 0·733	− 0·730 − 0·734 − 0·726	− 0·710	− 0·731	− 0·727
	Ditto, corrected values .	− 0·745	− 0·699	− 0·680	− 0·708	− 0·719	− 0·739	− 0·733	− 0·701	− 0·735	− 0·727
	Normalised	− 0·744	− 0·714	− 0·713	− 0·696	− 0·707	− 0·735	− 0·737	− 0·729	− 0·689	− 0·737
	Hardened .	− 0·745	− 0·672	− 0·685	− 0·639	− 0·655	− 0·744	− 0·656	− 0·743	− 0·745	− 0·759
O-Potentials, E_O.	As rolled .	+ 0·311	+ 0·311	+ 0·308	+ 0·310	+ 0·310	+ 0·311	+ 0·308 + 0·310 + 0·310	+ 0·310	+ 0·310	+ 0·310
	Normalised	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311	+ 0·311
	Hardened .	− 0·641	+ 0·295	+ 0·273	+ 0·308	+ 0·279	+ 0·308	+ 0·306	+ 0·278	+ 0·307	+ 0·306

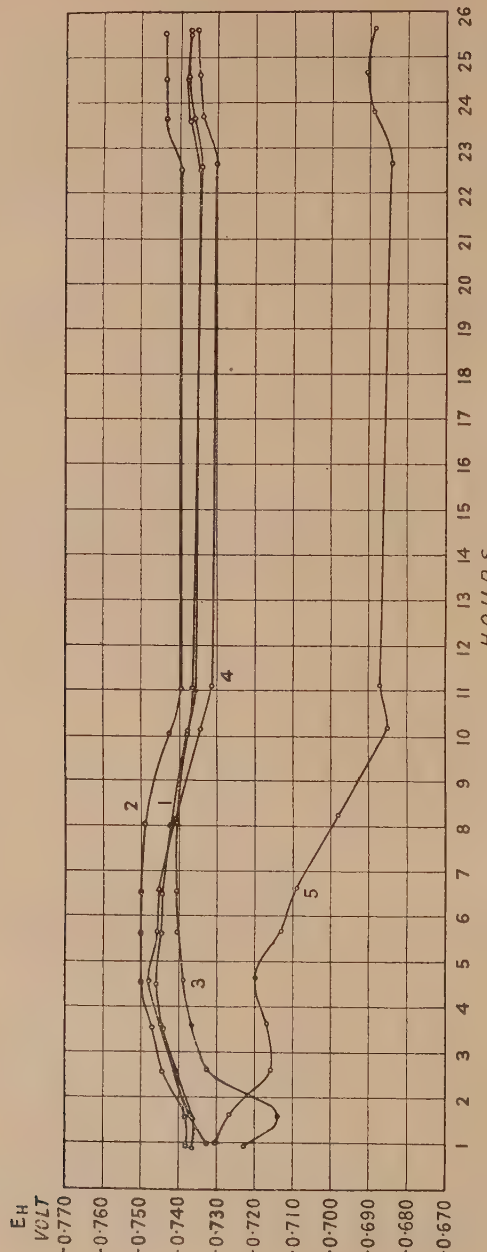

FIG. 9.—H-Potential Time Curves for Normalised Stainless Steels.

The figures given in Table VI. are plotted in Fig. 11 (*a*), and show the influence of varying chromium content, with an approxi-

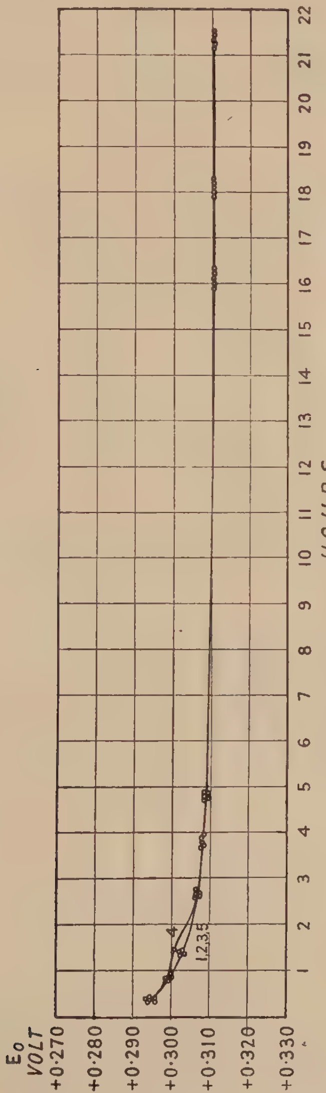

FIG. 10.—O-Potential Time Curves for Normalised Stainless Steels.

mately constant carbon content of 0·04 to 0·08 per cent. Fig. 11 (*b*) shows the influence of varying carbon content, with

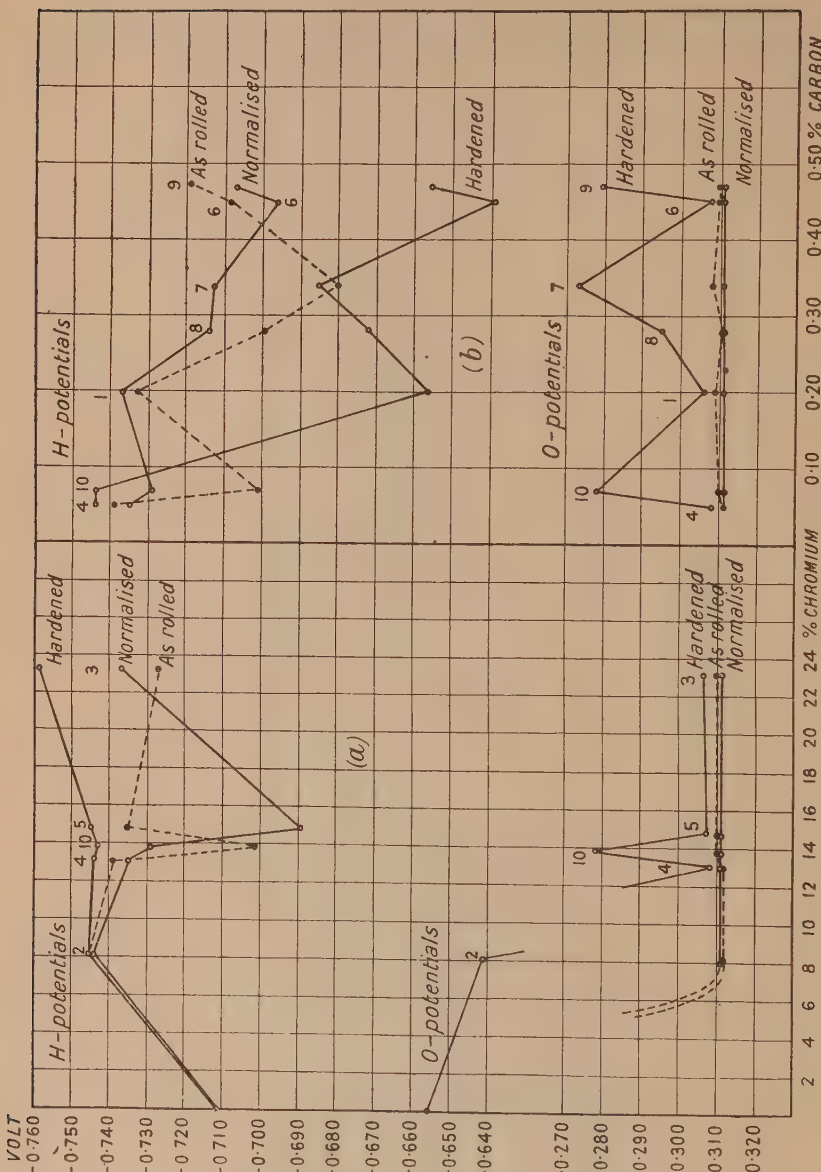

FIG. 11.—H- and O-Potentials of Stainless Steel containing—

(*a*) About 0·06 per cent. Carbon and 8–23 per cent. Chromium.
(*b*) About 13 per cent. Chromium and 0·05 to 0·47 per cent. Carbon.

an approximately constant chromium content of about 13 per cent.

After exposure to the oxygen-free solution all the specimens were entirely unaffected; after the addition of hydrogen peroxide the hardened steel No. 2, containing 8·5 per cent. chromium, was uniformly corroded, while all the others were just as bright as before.

Discussion of Experimental Results from Stainless Steels. Influence of Chromium.

Unquenched Specimens.

H-Potential, E_H.—As evidenced by Fig. 11 (*a*), E_H first rises considerably with increasing chromium content. The specimen containing 8 per cent. chromium shows a maximum of $-0·745$ volt. *Very near* 13 *per cent. chromium there is a sudden fall in* E_H, *down to about* $-0·70$ *volt*; after that there is a further increase in E_H.

Between the "as rolled" and normalised conditions of steel No. 5 there is a considerable difference; on the whole, however, these two states differ but slightly.

O-Potential, E_O.—The values of E_O for the "as rolled" and normalised steels lie even closer together than do those of E_H.

As a matter of fact, all the E_O values found lie extremely near the very low or "noble" value, $E_O = +0·311$ volt.

This value approaches rather near to that found by Tammann and Sotter [12] in a 0·1–*N* sulphuric acid, viz. $E = +0·6 - 0·286 = 0·314$ volt.

Similarly, Strauss [13] found a potential value $+0·2$ volt in 1–*N* ferrous sulphate solution against a 0·1–*N* calomel electrode; referred to a 1–*N* calomel electrode, this gives $E = +0·2 + 0·052 = +0·25$ volt.

If, consequently, the accord seems to be fairly good for E_O, the last-named author's values, which are comparable with E_H, are fairly low: $E = -0·6 + 0·052 = -0·55$ volt. This low value no doubt is due to the presence of some oxygen; this might also explain why Strauss did not observe the increase of E_H due to chromium, which actually occurs.

Quenched Specimens.

H-Potential, E_H.—The E_H of the quenched specimens, as seen in Fig. 11 (*a*), increases in a fairly regular way with increasing chromium content. The greatest value of this increase occurs apparently at a chromium content of about 8 per cent., giving $E_H = -0 \cdot 745$ volt; E_H, however, rises further to a value of $-0 \cdot 759$ volt for 23·2 per cent. chromium.

O-Potential, E_O.—E_O suffers for 8 per cent. chromium a decrease to $-0 \cdot 640$ volt; for higher chromium contents the E_O rises very nearly to the value found for the unquenched specimens, with the exception of steel No. 10, containing 13·80 per cent. chromium. The reason for its deviating will be discussed later; the fact that this steel has a slightly higher silicon content than the steels containing about 13 per cent. chromium hardly gives any explanation, although the hypothesis that silicon raises E_O might find some support also in the behaviour of the carbon steels, Nos. 2 and 3 (*cf.* Fig. 7). Of course, knowing the close connection between the passive state and the oxygen content, the contrary would rather be expected.

Influence of Carbon.

Unquenched Specimens.

H-Potential, E_H.—As may be seen in Fig. 11 (*b*), there are very irregular differences between the specimens as rolled and those normalised. On the whole, however, the normalised specimens possess a slightly higher E_H value. For both, E_H is found to decrease considerably, though in an irregular way, with the increasing carbon content.

O-Potential, E_O.—There is practically no difference between the E_O values of the specimens as rolled and those normalised, though the latter give the value $+0 \cdot 311$ volt without any variation.

In the same way as the E_O value ($+0 \cdot 311$ volt) of the unquenched specimens containing 0·04 to 0·08 per cent. chromium is not influenced by the chromium content beyond 8 per cent., so E_O is not influenced by the carbon content in a 13 per cent. chromium steel.

Quenched Specimens.

H-Potential, E_H.—E_H is found to be lowered in a very conspicuous way, from a value of $-0\cdot745$ down to $-0\cdot64$, with an increasing content of carbon. This lowering of E_H is rather irregular, it is true, but a comparison between steels Nos. 7 and 6, which differ practically only in carbon content, illustrates this influence of carbon in a typical way.

O-Potential, E_O.—Certain irregularities also occur here; they

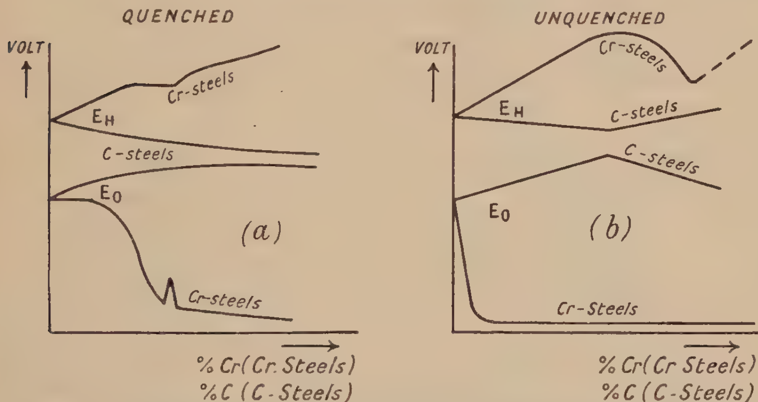

FIG. 12.—Schematic Diagram of the H- and O-Potentials of Carbon and Chromium Steels.

(*a*) Quenched. (*b*) Unquenched.

are, however, found to correspond closely with the irregularities in E_H.

In order better to illustrate the matter, Fig. 12 (*a*) and (*b*) has been drawn to show, though in a schematic way, the influence on E_H and E_O of increasing chromium and carbon contents respectively, for quenched and unquenched specimens. The figure illustrates the fact that the curves for E_H and E_O are, on the whole, "antibate."

RELATION TO SPECIFIC VOLUME.

Some additional light is thrown on the preceding discussion by an inspection of the specific volumes of the stainless steels

given in Table III. and represented graphically in Fig. 13 (*a*) and (*b*). For algebraical reasons, specific volume, of course, is much to be preferred to specific gravity for a rational discussion.

It is seen from Fig. 13 (*a*) that there is no sensible difference

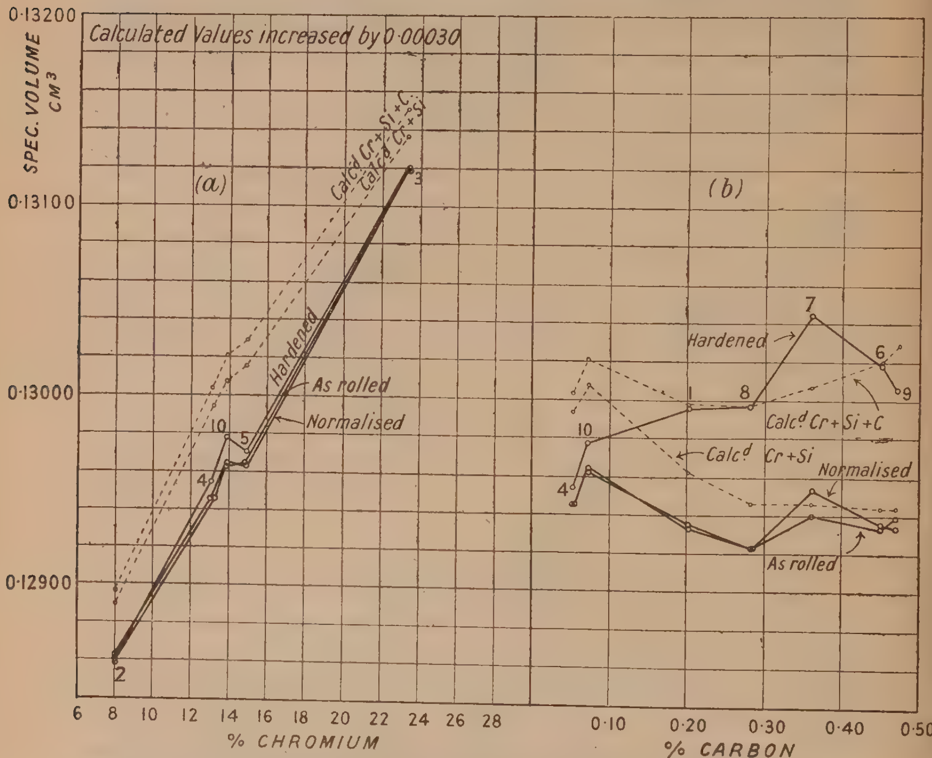

FIG. 13.—Specific Volumes of Stainless Steels containing :
(*a*) About 0·06 per cent. Carbon and 8 to 23 per cent. Chromium.
(*b*) About 13 per cent. Chromium and 0·05 to 0·47 per cent. Carbon.

between the specimens as rolled and as normalised. Likewise in Fig. 13 (*b*) the difference is very slight. Much more important, however, is the fact brought out by Fig. 13 (*a*) that there is practically no difference between quenched and unquenched specimens of stainless irons containing a very low carbon content. This would hardly be the case if chromium did not form a solid solution after every heat treatment, when the carbon content is

low. Fig. 13 (*b*) shows that at a constant chromium content of about 13 per cent. the specific volume is considerably higher in the hardened state.

Further, it is interesting to find that in Fig. 13 (*a*) No. 10 occupies an exceptional position, as was also the case for E_H and E_0 in Fig. 11 (*a*). Now, in this case it is possible to check whether its position is due to the slightly higher silicon content of No. 10 or not. As a matter of fact, it was shown by Benedicks [15] (*loc. cit.*, p. 30) that the specific volume, being an additive property, may be calculated with a high degree of precision. The present data, which indicate a strictly linear increase of specific volume with increasing chromium content, show that 1 per cent. chromium increases the specific volume of iron by 0·000165 cubic centimetre. Consequently the following values are available :

Element.	Increase in Specific Volume of Iron Caused by 1 per Cent. Addition.
Manganese	0·00006
Chromium	0·000165
Silicon	0·00117
Carbon	0·0018
(Aluminium)	(0·0025)

This allows of the calculation of the specific volume of the stainless steels. The specific volume of pure iron, as evaluated in this connection, was about 0·12700 ; in order that the calculated values in the diagram should not be confused with those observed, this value has been increased here to 0·12730. In Fig. 13 are plotted (dotted lines) the specific volumes so obtained : (1) for pure Fe + Cr + Si ; (2) for Fe + Cr + Si + C. It will be seen that the harmony between the observed and calculated points is very satisfactory, both in Fig. 13 (*a*) and, generally, in Fig. 13 (*b*). This bears out the general exactitude of the analyses and homogeneity of the metal.* It may be noted here that the irregularity shown by No. 10 in Fig. 13 (*a*) is slightly more accentuated than it would be if due to the Cr + Si content.

* As regards the high value shown by No. 7, it was found that this was probably due to hardening cracks occurring in this specimen ; to some extent, hardening cracks were also found to occur in Nos. 1, 8, 6, and 9. This explains the volume surplus in the hardened specimens. The slight surplus of No. 7 in the unquenched condition is probably due to a slight surface fault occurring there.

RELATION TO ELECTRIC RESISTIVITY.

These conclusions are substantiated by an inspection of the resistivity * data represented in Fig. 14 (*a*) and (*b*). It will be

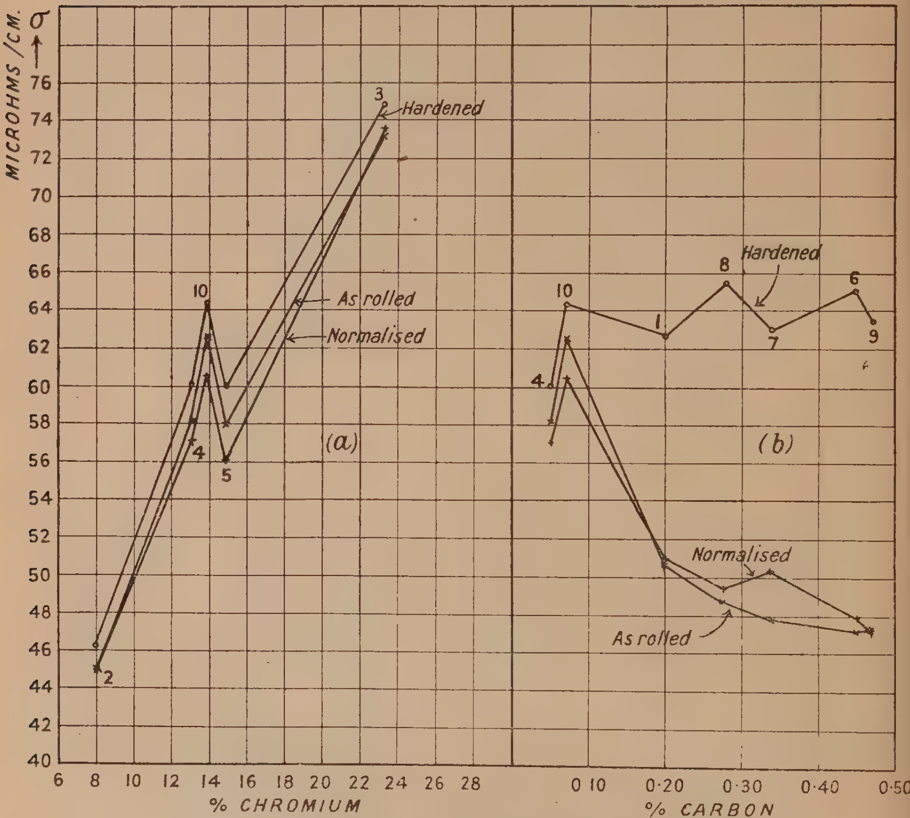

FIG. 14.—Electrical Resistivity of Stainless Steels containing:
(*a*) About 0·06 per cent. Carbon and 8 to 23 per cent. Chromium.
(*b*) About 13 per cent. Chromium and 0·05 to 0·47 per cent. Carbon.

seen that there is not much difference between the specimens as rolled and normalised. It is much more noteworthy, however, that the *unquenched specimens possess practically the same specific*

* Resistivity data are given, though only for higher carbon contents than those occurring here, by C. A. Edwards and A. L. Norbury, *Journal of the Iron and Steel Institute*, 1920, No. I. p. 447.

resistance σ as the hardened specimens (Fig. 14 (*a*)). The conclusion to be deduced, that chromium occurs in a dissolved state at a low carbon content, even after slow cooling, is well supported by Fig. 14 (*b*); as seen here, the unquenched specimens containing about 13 per cent. chromium possess a resistivity as high as about 62 microhms per centimetre, at a very low carbon content. *On increasing the carbon content, this resistivity value, however, is considerably lowered.* The addition of an increasing amount of carbon apparently causes a part of the dissolved chromium to be precipitated.

This interpretation is further supported, in a more quantitative way, by the figures in Table VII.

TABLE VII.—*Increase in Electric Resistivity.*

No.	Carbon.	Δσ Due to Carbon.	Δσ Actually Occurring.
	Per Cent.	Microhms per Centimetre.	Microhms per Centimetre.
10	0·07	1·9	3·0
1	0·20	5·4	11·8
8	0·28	7·5	16·0
7	0·34	9·1	12·6
6	0·45	12·1	17·4
9	0·47	12·6	16·2

The figures in the third column give the increases in σ which would result from the carbon alone going into solution. In the fourth column are given the differences in σ actually occurring between the quenched and unquenched states. It will be seen that the latter figures are much higher, and this fact must be due to a considerable part of the chromium being precipitated at the same time as the carbon, on slow cooling. According to Westgren,* the occurrence of a cubic carbide, Cr_4C, must be here conceded.

This behaviour of low-carbon stainless steels is in agreement with some results obtained recently by Kalling and Pagels.[16]

It may be seen from this analysis that the irregularity met with in the potentials near 13 per cent. chromium may also be traced in the specific volumes, and that it is particularly accentuated in the electric resistance. It must no doubt be

* Unpublished result.

attributed to some constitutional influence of chromium on iron. It appears most probable that the irregularity is due to the iron occurring only as α-iron during cooling, when the chromium content exceeds 13 or 14 per cent., while at lower contents it passes through a γ state. This view has recently been supported by a detailed investigation by Bain.[17] It appears quite reasonable that such a difference, probably also connected with grain-size, may influence the electrochemical potentials.

Rusting Tendency of a Stainless Steel.

Of a considerable number of preliminary experiments, made under varying circumstances, and in which a 1–N potassium

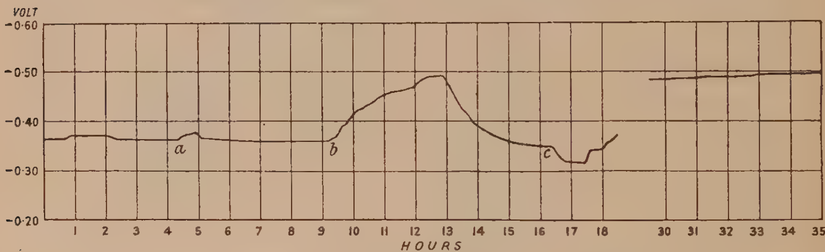

Fig. 15.—Registered Potential Time Curve for a Stainless Steel in 1–N KCl Solution.

chloride solution, not carefully freed from air, was used as an electrolyte, only one needs to be mentioned here.

A 0·5-millimetre "stainless" steel plate (presenting a free surface of twice 3 millimetres × 15 millimetres), containing carbon 0·10 and chromium 13 per cent., was made the electrode in a 1–N potassium chloride solution, and the e.m.f. obtained against a 1–N calomel electrode was compensated and registered by a Callendar recorder. As a rule the recorded curves showed very small variations, as was to be expected for a passive state. In one case, however, the potential gave evidence of a rather sudden change, as seen in Fig. 15. At a a small change in a less noble direction may be noted. At b, however, a considerable change occurs, also corresponding to a less noble potential. After $3\frac{1}{2}$ hours, without any external change, a return is to be seen, the original nobler value being regained after about six hours. The change at c is due to some carbon dioxide-free air being blown

against the specimen. During the following sixteen hours the potential value returned to the maximum value.

These irregularities were found to coincide with a visible formation of rust on one-third part of one side of the specimen, which was observed before the point *c* was reached. This observation shows that a rusting of a "stainless steel" may set in, but the metal may return, at least for some time, to its nobler or passive state. This might be considered as a new illustration of the well-known influence of chlorine ions, acting against a stable passive state [18]; as a matter of fact, the total amount of the potential change is much inferior to those found in ferrous sulphate solution.

A Photo-Cell Made of Stainless Iron.

It has already been pointed out that some irregularities, otherwise unexplained, amounting to 10 to 15 millivolts, occurred in the values of E_H for stainless steels, and also to some extent in the determination of E_0 in carbon steels; they were attributed to the influence of the light. Though this explanation no doubt was quite satisfactory, as they were found to be closely connected with the sunny time of the day, it was considered to be of some interest to examine the point more closely. Experience proves that an aqueous solution of ferrous sulphate may be preserved indefinitely in the light, while in a dark room a ferric sulphate is quickly precipitated from the solution. Hence, the action of light must be that of displacing the equilibrium between the different ions in the direction of the ferrous ion. Now, in the determinations made with an oxygen-free sulphate solution, the content of ferric ions must have been extremely low; consequently, light could scarcely have any appreciable influence. On the other hand, in the presence of some oxygen, it is to be expected that the reducing action of light will exert some sensible influence. This was actually found to be the case.

Further, the passive state of iron, according to many writers, being connected with the presence of ferric ions, it is natural to suppose that even in an oxygen-free sulphate solution surrounding a stainless steel a definite amount of ferric ions will be found. Hence, this solution may be light-sensitive. This condition was

tested in the following way. Two insulated strips of stainless iron (carbon 0·10, chromium 13·0 per cent.) were placed in the same plane in a jar (" cuvette "). The latter was made air-tight, and by means of two tubes it could be filled with hydrogen or with oxygen-free sulphate solution in the same way as in the E_H determinations. The two strips were connected to the moving-coil galvanometer already mentioned.

This little apparatus was actually found to constitute a photo-cell. When one strip was illuminated with a beam of sunlight, an immediate deflection of the galvanometer was obtained, amounting to about 20 millimetres, in one or other direction, according to the side of illumination. This of course proves the correctness of the interpretation in question. Similar photo-cells are known for silver, copper, and tin,[19] but, so far as is known, not for iron.

Summary.

1. The present investigation reports on the electrochemical potentials of some carbon and chromium (stainless) steels in different conditions, which occur :

(*a*) In a neutral (0·82–*N*) ferrous sulphate solution, carefully purified from free oxygen ; " H-potential," E_H.

(*b*) In the same solution in a partly oxidised state, obtained by the addition of a definite quantity of hydrogen peroxide ; " O-potential," E_O.

A description is given of a rational method of preparing the solutions, and also of some other practical details. The figures given in volts, and accurate to a few units of the third decimal place, are those obtained against a normal calomel electrode.

2. E_H possesses, in all the cases examined, a higher, *i.e.* more negative, or baser, value than E_O. As a rule, E_H and E_O are antibate (influenced by additions in opposite ways).

3. The purest iron investigated was found to give (for a 1–*N* ferrous sulphate solution) $E_H = -0{\cdot}708$ volt, which is in close agreement with the previous values obtained by Richards and Foerster. At a very low carbon content E_O was found to be approximately $E_O = -0{\cdot}62$ volt.

4. For carbon steels the following results were obtained (see Fig. 12) :

(*a*) In unquenched specimens, E_H is slightly lowered with increasing carbon content up to 0·9 per cent.; then a slight rise occurs.

(*b*) Quenching lowers (or renders nobler) the E_H values of a given steel; this effect increases with a higher quenching temperature. E_H is lowered with increasing carbon content down to $E_H = -0{\cdot}686$ volt for 1·35 per cent. carbon.

(*c*) For unquenched specimens, E_0 was found to rise considerably, though in an irregular way, with increasing carbon content up to 0·9 per cent.; at higher contents (at least above 1·20 per cent.) E_0 is again lowered.

(*d*) Quenching raises the E_0 values of a given carbon steel; this effect increases with a higher quenching temperature. E_0 rises considerably, though in an irregular way, with increasing carbon content.

(*e*) The difference between E_H and E_0 tends to vanish with an increasing carbon content as well as with increasing quenching temperature. A consequence of this is that *a differential aëration will exert a very slight influence on a high-carbon steel, if hardened at a sufficiently high temperature.*

5. For chromium (stainless) steels the following points may be noted:

(*a*) For unquenched specimens (containing 0·04 to 0·08 per cent. carbon) E_H rises considerably on the addition of 8 per cent. chromium (from $-0{\cdot}711$ to $-0{\cdot}744$ volt), the potential then being sensibly baser than that of iron or carbon steel. On further addition of chromium, a lowering of E_H takes place, *which is particularly prominent when the chromium content reaches* 13 to 14 *per cent.* With still higher chromium contents, E_H rises again. At a constant chromium content of 13 per cent., E_H is lowered considerably by an increasing carbon content.

(*b*) In quenched specimens, E_H rises with increasing chromium content. On the other hand, E_H is very materially lowered for steels containing about 13 per cent. chromium, by an increasing carbon content, down to a value as low as $-0{\cdot}55$ volt.

(*c*) For unquenched specimens, E_0 possesses a remarkably constant value, $E_0 = +0{\cdot}31$ volt, which is unaffected by chromium (beyond a content $\gtreqqless$ 8 per cent.) and by carbon.

(*d*) In the quenched specimens containing 0·04 to 0·08 per

cent. carbon, E_0 is lowered to $-0 \cdot 64$ volt at $8 \cdot 05$ per cent. chromium, and generally to $+0 \cdot 31$ for higher chromium contents.

In the quenched specimens containing about 13 per cent. chromium, E_0 varies between $+0 \cdot 275$ and $+0 \cdot 308$ volt.

6. The specific volumes of the stainless steels were found in most cases to correspond closely with calculated values. Very regular results were also obtained for the electrical resistivity, these being typical for the constitution of the iron-chromium alloys.

Both sets of results agree with the sudden change occurring in E_H and E_0 near 13 per cent. chromium, a change probably related to the fading out of the γ-region with higher chromium content (C. Bain).

7. A "stainless" steel (carbon 0·10, chromium 13 per cent.) immersed in 1–*N* potassium chloride solution was found to assume temporarily a higher, or active, potential. Thereby a visible rusting occurred.

8. A photo-cell was constructed by means of two strips of stainless steel, profiting by the observation that a stainless steel specimen, immersed in a ferrous sulphate solution, is light-sensitive. The light actually causes an increase in E_H, *i.e.* it renders the steel slightly baser. To a certain extent the potential of a carbon steel was also found to be affected by light, provided some ferric ions were present. In the same way as the action of light cannot be disregarded in the corrosion of copper [18] (*loc. cit.*, p. 109), it probably also exerts at least some influence on the rusting of iron.

This research has been carried out with the aid of two successive grants from Jernkontoret, Stockholm. The authors also wish to express their gratitude to Consul-General A. Axelson Johnson and Count B. Kalling, Met.Eng., Avesta, for presenting a selection of stainless steels; and to Mr. P. Sederholm, Fil.Kand., for valuable assistance.

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CORRESPONDENCE.

Mr. U. R. Evans wrote that the results obtained by the authors appeared to be of the highest importance, and cleared up numerous points which had hitherto been in doubt. They showed, for instance, quite clearly that the " noble " values for the potential of stainless steel obtained by some earlier workers were not intrinsic properties of stainless steel itself, but were due to the presence of oxygen ; in the absence of oxygen, the potential of stainless steel had a value fairly near to that of pure iron. Evidently, stainless steel was intrinsically a " reactive " material, but owed its resistance to corrosion to " air-passivity."

Recent work [1] had shown that even pure iron could, under some conditions, display " air-passivity," but the passivity was of a far less reliable character than that produced by the action of air on stainless steel. That was almost certainly due to the fact that the oxide produced on pure iron was more permeable than that produced on the chromium alloy. The difference in the specific permeability of the oxides produced upon the two materials was illustrated by the fact that, when the materials were heated in air, a higher temperature was needed to produce a film showing a given " temper tint " in the case of the chromium alloy than in the case of an ordinary steel. The same difference in permeability no doubt accounted for the fact that, whereas with ordinary iron the potential was shifted less than 0·1 volt by the presence of oxygen, the potential of chromium steel might be shifted as much as 1·0 volt, as the authors had shown. The deposition upon an electrode of a film freely permeable to all ions should not cause any displacement of the potential ; but if a film were deposited which obstructed the passage of ions, a shift would in general occur, as previously pointed out.[2] The film produced by oxygen on chromium steels obstructed the passage more than that on ordinary steels, so that the shift of potential was greatest in the case of chromium steels ; but chlorine ions could penetrate where the polyatomic ions could not, and thus in the presence of chlorides the potential might sometimes assume a more reactive value, and at the same time rusting might occur.

Another interesting result of the authors' work was the explanation of the comparatively high resistance to corrosion of quenched high-carbon steel, such as was used for razors. But although the differential-aeration E.M.F. was much lower than in the case of low-carbon steels, the figures given showed that it did not completely vanish, and differential-aeration phenomena might be expected under certain favourable circumstances. That was actually found to be the case. Three years ago, in a lecture to the Oil and Colour Chemists Association, he (Mr.

[1] *Nature*, 1926, vol. cxviii. p. 51.
[2] *Transactions of the Faraday Society*, 1924, vol. xix. p. 789.

Evans) showed a lantern slide of a razor blade exhibiting quite clearly the differential-aeration effect.[1] The blade had been hung in potassium chloride solution, and showed marked corrosion at the points least accessible to oxygen, namely, at the bottom and also along the line where the suspending thread had pressed against the metal; over the area most accessible to oxygen it was quite uncorroded.

Dr. W. H. HATFIELD (Sheffield) wrote that valuable work had been carried out with a view to obtaining quantitative data on the effect caused by oxygen in corrosion phenomena. In all cases the effect was apparently to make the material "nobler," and was evidently in support of the corrosion theory outlined by Evans. The greater resistance to corrosion of chromium steels was shown by the greater alteration in the E_0 values from a high negative to a high positive value. Since, according to Evans's theory, such corrosion was due to electrolytic currents caused by differential areation, it would be interesting to see what change, if any, in the E_0 values was caused by differences in oxygen content, and whether such changes were less in the case of chromium steels than in carbon steels. In the case of tests with varying amounts of H_2O_2 on a carbon steel (p. 188), initial differences were noticeable, and they were appreciable after one hour. Were similar tests made on a stainless steel specimen?

As to the values obtained, he (Dr. Hatfield) had only one from his large batch of tests which could be directly compared with those of the authors. For electrolytic iron in a $0 \cdot 93$–N $FeSO_4$ solution, he obtained a value against a N calomel electrode of $-0 \cdot 696$ volt, which compared favourably with theirs of $-0 \cdot 708$ volt for a N $FeSO_4$ solution.

Although the effect of the use of varying grades of emery-paper was examined, it appeared that no study of the possible difference in the behaviour of old and freshly prepared surfaces was made. That would have been an interesting addition to the paper.

He thought that the physical determinations made on the samples were of considerable value, apart from their use in the paper.

Professor W. PALMÆR, D.Sc. (Stockholm), wrote that, concerning many of the numerous measurements of potential differences which had been published in papers on the corrosion of metals, a considerable uncertainty prevailed as to what had really been measured. That referred to the question whether the potential difference observed belonged to the pure metal, to a perhaps invisible oxide layer, or to a metal on the surface of which some gas was occluded, and also to the composition of the solution. The following remarks bore upon an explanation of some of the authors' results, the interpretation of which was not expressly given by the authors.

With regard to the measurements of the potential difference between

[1] *Journal of the Oil and Colour Chemists Association*, 1923, vol. vi. p. 150.

nearly pure iron and a solution of ferrous sulphate (Table IV.), the authors had arrived at results which, as they stated, agreed with those of Richards and Behr, jun., and thus afforded a new and valuable confirmation of earlier determinations of that important constant. They had found an ingenious way of shortening the time needed for the final neutralisation of a solution of ferrous sulphate to which sulphuric acid and filings of electrolytic iron had been previously added to reduce the small amount of ferric salt contained in the ferrous sulphate; for that purpose they added barium hydroxide to the solution after its reduction. They then said: "As a matter of fact, the addition of barium hydrate produces strict neutrality, and the excess barium hydrate and the barium sulphate quickly sink to the bottom." That was to be explained in the following way: Evidently, by the addition of barium hydrate—which must be supposed to have been used in only a *slight* excess—the remaining sulphuric acid was neutralised, and barium sulphate precipitated. Then the small quantity of barium hydrate still remaining reacted with a small part of the ferrous sulphate, giving barium sulphate and ferrous hydrate. Most of the latter was precipitated too, of course, but a saturated solution of ferrous hydrate remained. It was not perfectly clear whether by a strictly neutral solution was meant a solution in which the concentration of the hydrogen ions was the same as in pure water, or as in a pure solution of ferrous sulphate, in which the concentration of the hydrogen ions was somewhat higher on account of hydrolysis. The solution which the authors had prepared, however, was evidently slightly alkaline, really as much so as corresponded to the solubility of ferrous hydrate. According to the measurements of H. Sundberg, published in a preliminary report on the extended researches concerning the corrosion of metals which the present writer had lately carried out,[1] the solubility of ferrous hydrate in pure water at $+18^\circ$ C. amounted to about $1 \cdot 3 \times 10^{-5}$ gramme-molecules per litre, the molar concentration of the hydroxyl ions thus amounting to about $2 \cdot 5 \times 10^{-5}$, instead of about $0 \cdot 8 \times 10^{-7}$ in pure water. The concentration of hydrogen ions in a solution of ferrous hydrate in pure water would be, therefore, about $2 \cdot 6 \times 10^{-10}$ instead of $0 \cdot 8 \times 10^{-7}$ in pure water, and in the solution of ferrous sulphate used by the authors it might be about $0 \cdot 2 \times 10^{-7}$. He (Professor Palmær) wished, however, to point out that the difference in question could not have any great effect upon the potential difference between iron and a solution of ferrous sulphate, which the authors seemed to fear, since they said: "Naturally the strict neutrality of the solution is indispensable."

The main purpose of this communication was to throw light upon the real bearing of the potential differences measured by the authors and characterised by them as "O-potentials," that is, oxygen potentials. For measuring them they added, in most cases, a quantity of hydrogen

[1] W. Palmær, *Korrosion und Metallschutz*, 1926, vol. ii. p. 1.

peroxide to a solution of ferrous sulphate, and then measured the potential difference between iron immersed in that solution and a 1–N calomel electrode.

It was misleading to use the expression O-potential in such a general way as the authors evidently did. Every oxidising substance, as was well known, had its own oxidising potential or depolarising effect, and thus those potentials were different for oxygen and for hydrogen peroxide. Further, by the addition of hydrogen peroxide to the solution of ferrous sulphate, ferric salts were formed, and they possessed a third oxidising potential.

The authors used a $0 \cdot 82$–N solution of ferrous sulphate. Supposing that this meant that the solution contained $0 \cdot 82$ gramme-equivalents —and not gramme-molecules—of ferrous sulphate per litre, it could be calculated from the stated quantity of peroxide added (p. 191) that a little more than half of the ferrous sulphate had been oxidised to ferric compounds. Since the solution of ferrous sulphate was nearly neutral, that oxidation at the first step must have led to the formation of basic ferric sulphate, which would then have been hydrolysed so that ferric hydroxide and free acid were formed. In that manner the solution perhaps departed somewhat from strict neutrality. The statements of the authors (p. 189) agreed with that, as they said that the peroxide first gave a dark red colour to the solution (which must be attributed to the appearance of the product of hydrolysis in the colloidal state) and that somewhat later a precipitation occurred in the solution. That precipitate was in all probability ferric hydroxide.

Hence, if the potential differences measured by the authors were characteristic of some oxidising agent, they most probably should be supposed to represent the oxidising potential of ferric salts, since the peroxide was practically completely consumed and oxygen could occur only as a decomposition product of the peroxide. The values obtained by the authors showed, however, that it could not be the oxidation potential of ferric salts which they had measured.

The concentration of ferrous ions, after rather more than half the initial amount of ferrous sulphate had been oxidised, might be estimated at about $0 \cdot 1$ gramme-equivalent—that is, $0 \cdot 05$ gramme-ions—per litre. The concentration of ferric ions might be supposed to be at least as great as corresponded to the solubility of ferric hydrate, that is, about 10^{-6} gramme-ions per litre,[1] while, on the other hand, it could not be supposed to exceed the concentration of ferrous ions, which was therefore to be taken as the upper limit. From what was known as a result of the measurements by Peters,[2] Auerbach and Luther in their well-known compilation of electromotive forces [3] deduced the potential difference of an electrode in a solution containing ferrous and ferric ions in the

[1] Almkvist, *Zeitschrift für anorganische Chemie*, 1918, vol. ciii. p. 240.

[2] *Zeitschrift für physikalische Chemie*, 1898, vol. xxvi. pp. 193–236.

[3] "Messungen elektromotorischer Kräfte," 1911 and 1915 (W. Knapp, Halle a./S.).

same concentration against the normal hydrogen electrode to be + 0·75 volt, the electrode in the solution of iron salts thus being charged positively. From that it was easily calculated that if the potential differences measured by the authors against a 1–N calomel electrode had corresponded to the oxidising power of ferric salts they would have amounted to something between + 0·20 and + 0·47 volt. The authors found the potential differences of unquenched carbon steels against a 1–N calomel electrode to be between − 0·70 and − 0·71 in a pure solution of ferrous sulphate, and between − 0·62 to − 0·66 volt in the oxidised solution (p. 194). Though the small changes, amounting to 0·04 to 0·09 volt, went in the *direction* expected they did not at all agree quantitatively, the difference between the experimental and calculated values in the oxidised solutions amounting to about 0·8 to 1·1 volt. Thus it was not the oxidising power of ferric salts which had caused the potential differences measured by the authors.

As it seemed unlikely that the small traces of oxygen and hydrogen peroxide occurring in the solution might have caused the oxidising potential of either of those substances to have been measured—since the ferric salts, occurring in much greater quantity, did not impress their potential on the electrode—it remained to suppose that the potential differences measured were due to some changes of the surface of the electrode. The fact was that Peters used a platinum electrode in his measurements and not an iron electrode. Richards and Behr, jun., however, made measurements with an iron electrode in a solution of a ferric salt (chloride) and got results similar to those of the authors.[1] Thus the results of several authors indicated that the result was due to the iron electrode.

It might perhaps be supposed that what interfered was adsorbed oxygen, but that might have been present in the experiments of Peters, too, in about the same small quantities, and therefore it was not very likely that the potential of adsorbed oxygen had been measured in either case, since the figures of Peters differed so strongly from those observed by Richards and Behr and by the authors.

It remained, then, as the most probable supposition that (hydrated) *ferric oxide* had been formed on the surface of the iron and that what was measured was the potential difference of such an electrode against the solution in question. That was confirmed by the authors' statement (p. 191), that the specimens immersed in the pure solution of ferrous sulphate were entirely uncorroded, but those immersed in solutions to which hydrogen peroxide had been added were visibly corroded. It must be pointed out, however, that it seemed improbable that the potential differences measured were the same as those belonging to a homogeneous iron oxide electrode—which was not easy to prepare—but might be affected by the presence of unaltered iron surfaces; also the concentration of the ions, which might affect the potential of an

[1] *Zeitschrift für physikalische Chemie*, 1907, vol. lviii. p. 322.

iron oxide electrode, was undetermined. Only doubtful use of those values could therefore be made when dealing with theoretical or practical questions concerning corrosion. In that connection reference must be made to the authors' statement on p. 179 that it was of special importance to know the potential of a metal in a solution containing oxygen. From the standpoint of the theory of local galvanic elements, which he (Professor Palmær) had developed, it was important to know the effect that oxygen produced at the cathode as depolariser, but " the potential of a metal in a solution containing óxygen "—a very vague notion indeed—had no special bearing according to that theory or any other theory as yet proposed.

The conclusions here drawn were strongly confirmed by the fact that the authors, with a *stainless chromium steel which did not corrode* in a solution to which hydrogen peroxide had been added, found potential differences *which lay between the limits, calculated above, for the case in which it was the oxidising power of ferric salts, which was measured* (*cf.* pp. 190 and 203). Using either air or hydrogen peroxide as the oxidising agent, they obtained $+0\cdot25$ to $+0\cdot30$ volt against a 1–N calomel electrode (see Fig. 3), while the calculation made above showed that the potential difference should lie between $+0\cdot20$ and $+0\cdot47$ volt. For a number of stainless chromium steels they then found the final value $+0\cdot31$ volt, which also fell between the limits calculated.

Further, it might be pointed out that when peroxide was added the authors first observed rapid changes of the potentials towards algebraically greater values even with carbon steels, but that later the changes of the potential differences reversed their directions when approaching the final values, which did not differ much from those obtained without peroxide (*cf.* Figs. 2B and 5). For that, of course, the simple explanation might be that the electrode was tending to assume the potential corresponding to the oxidising power of ferric salts, but that that process had been interrupted by the production of iron oxide on the surface of the electrode.

Finally, he wished to make an historical comment. The authors stated that Ericsson-Aurén was the first scientist to take up experimentally the electro-chemical theory of de la Rive. Ericsson-Aurén, however, only pointed out that his purpose was to get more precise conditions by using weak acids when measuring the dissolving velocity of zinc—an idea which had proved most fruitful, since his measurements were the first which allowed of a theoretical treatment. That was carried out later by him (Professor Palmær) in collaboration with Ericsson-Aurén, and in summing up his results the latter gentleman expressed the opinion that the dissolving velocity was probably determined by two factors—namely, local electric currents and the direct chemical effect of the acid on the zinc.[1] He (Professor Palmær) was, however, able to show that the results could be explained solely by the

[1] *Zeitschrift für anorganische Chemie*, 1901, vol. xxvii. pp. 215, 251.

theory of local galvanic elements, and to build up in a quantitative way the theory which had been put forth qualitatively by de la Rive.[1]

Professor Benedicks wrote in reply that he very much appreciated the kind remarks of Mr. Evans, whose lucid description of the action of the surface layer corresponded with the opinion held by the authors. His statement that monovalent ions, such as those of chlorine, bromine, or iodine, could easily pass through such a surface layer and give rise to corrosion, while a polyvalent ion could not, was very interesting. The authors in no way disputed the fact that the attack of high carbon steels did occur on account of differential aeration; the point at issue only was that, judging from the figures obtained, such an attack must be much more difficult than it was in the case of unhardened specimens.

The authors thanked Dr. Hatfield for his communication. Regarding variations in E_0 of stainless steels at varying oxygen contents, it might have been useful to point out in the paper that those variations were apparently extremely small; consequently, differential aeration had a considerable influence in promoting corrosion only in that case when the oxygen supply was extremely small at some point. That explained why a short tube of stainless steel immersed in a 5 per cent. NH_4Cl solution might be entirely unattacked, except at its very lowest part, at a point in close contact with the beaker used; there a very narrow and deep corrosion might occur, and eat away the inner metal of the tube (as found in unpublished experiments made by Sköldberg). At such a place the oxygen content would be so low as to permit the metal to assume nearly its E_H value, which, as shown in the paper, was even less noble than that of pure iron: hence a deep corrosion due to differential aeration would occur at that particular spot, but not elsewhere.

In reply to Professor Palmær, whose interest in their paper was very gratifying, they would point out that "strict neutrality," said by them to be indispensable, was intended to mean "so nearly neutral" that no sensible error would be introduced into the determinations, as would be the case with the use of barium hydroxide, proposed by Sederholm. It was of no consequence whether the concentration of OH ions were $2 \cdot 5 \times 10^{-5}$ or $0 \cdot 8 \times 10^{-7}$—which was, of course, acknowledged by Professor Palmær.

It was true that the expression "O-potential" was somewhat vague, and implied only that the values were obtained in a solution which might contain free oxygen. It was considered suitable, however, because the factors influencing the potentials had never been elucidated in detail, either in the present or any other investigation. The analysis made by Professor Palmær showed very clearly the difficulties which

[1] *Cf.* W. Palmær, *Korrosion und Metallschutz*, 1926, vol. ii. p. 1, where the previous papers by Ericson-Aurén and the present writer also were quoted (*Zeitschrift für physikalische Chemie*, 1901, vol. xxxix. p. 1; 1903, vol. xlv. p. 181; 1906, vol. lvi. p. 689).

occurred. The expression "1–N solution" referred, of course, to gramme-equivalents, as was almost invariably the custom.

In accordance with Professor Palmær's supposition that a basic ferric sulphate was formed, the formula for the reaction must be as follows:

$$6FeSO_4 + 3H_2O_2 = \left[2Fe_3 \begin{cases} (SO_4)_3 \\ (OH)_3 \end{cases}\right] = 2Fe_2(SO_4)_3 + 2Fe(OH)_3.$$

According to that, the addition of the hydrogen peroxide gave rise to the red coloration, due to the direct formation of $Fe(OH)_3$ in the colloidal state, without the formation of any free acid. The red coloration was already explained, in the authors' opinion, by the primary reaction, and did not prove that hydrolysis occurred, implying the formation of free acid. There was, however, no doubt that hydrolysis did occur, producing free acid. That free acid, in their opinion, explained sufficiently well the corrosion observed after the addition of the hydrogen peroxide, and there seemed to be, consequently, little reason for attempting to explain it as being due to the formation of an iron oxide layer which might be supposed to be a more noble substance, so causing local electrolytic action. Professor Palmær's statement, that the potential of a metal in a solution containing oxygen had no bearing on the "galvanic element" theory as expounded by him, or any other theory as yet proposed, did not seem to be in good harmony with the influence exerted by differential aeration, the import of which was nowadays acknowledged.

His opinion that the presence of ferric ions gave a nobler potential, just as an oxide layer did, was shared by the authors. Those two factors must, of course, be expected to act in the same direction, even when both were present; Professor Palmær appeared to assume that the oxide layer would cause a less noble potential in the presence of ferric ions, but that assumption was scarcely supported. He admitted, just as the authors did, that the noble value of E_0 for carbon steel was due to an oxygen layer. That, *a fortiori*, ought to be the case for a chromium steel; consequently, a calculation based solely on the composition of the solution would hardly give correct results, especially in view of the 13 per cent. of chromium usually present. The agreement of the observed with the calculated values appeared to the authors to be possibly merely a matter of chance.

It should be noted that Ericsson-Aurén propounded the galvanic theory of de la Rive in the first introduction of his thesis. The fact that he also considered the possibility of a "purely chemical action" was no demerit, for that most direct action deserved not to be forgotten, even if experimental results so far obtained did not necessitate its consideration.

TESTING OF HARDENED STEEL.*

By AXEL LUNDGREN, Met.Eng.
(The Government Testing Institute, Stockholm, Sweden).

The manufacture of high-grade tool steel, partly in the form of bars or other semi-products, partly in the form of finished tools for metal and wood working and other purposes, is an important branch of the Swedish steel industry. Now both practical experience and scientific investigations have proved that the quality and endurance of the finished tool largely depend, not only on the original purity of the steel, but also on the kind of heat treatment it has undergone in the various stages of manufacture, and, moreover, on the temperature of hardening and the tempering temperature. Practical experience in the use of the tool and microscopic investigation of the steel have hitherto formed almost our only guides in judging the utility of the steel in most cases, and the need has been felt of applying regular mechanical tests which, as in the case of structural steel, may afford a rapid means of control of the material.

The Government Testing Institute in Stockholm, which, on behalf of the industry, is frequently called upon to determine the proper composition and treatment of tool steel, has endeavoured to devise a method of testing by which, in particular, the mechanical qualities of hardened tool steel may be determined more rapidly than is possible by means of practical cutting tests. The Swedish "Jernkontoret" has encouraged this endeavour by granting subsidies to the Government Testing Institute for carrying out such work.

The present paper gives the first results of this work, and contains:

I. Methods of testing the mechanical properties of hardened steel.

II. The influence of various methods of annealing, and of the resulting microstructures, on the mechanical properties of the steel after hardening.

* Received June 19, 1926.

III. The influence of the quenching and tempering temperature upon the mechanical properties of the steel.

In the performance of this investigation Mr. S. Strömgren, Met.Eng., has taken a very active part.

I. Methods of Testing the Mechanical Properties of Hardened Steel.

The chief requirements for tools, such as cutters, drills, or such like, intended for working on metals, wood, &c., are the following :

1. Great hardness, in order to be able to cut material without deformation or too rapid wear of the edge.
2. Great resistance to bending, so as to withstand the bending stress applied to the edge of the tool in the case of heavy cuts.
3. Great toughness, so as to obviate fracture in the case of sudden temporary overload, such as on meeting hard inclusions or segregations in the material.

For various kinds of tools combinations of these qualities are frequently requisite. In many cases one particular quality is of greater importance than the others, and it may be necessary that this quality be maintained or improved, even at the expense of the others. For example, a cutter for working steel must have great hardness in order to keep a good edge, and it cannot therefore be tempered as much as might be desirable for increasing the toughness. On the other hand, a saw, though it needs to be as hard as possible in order to preserve its cutting capacity and not wear too quickly, must combine hardness with pliability and toughness to withstand the stress of violent blows to which it may be exposed when, working at great speed, it comes in contact with hard knots. For this reason it must be tempered rather highly at the expense of hardness, so that it may have sufficient ductility and impact resistance.

For the manufacture of tools, or indeed of any hardened steel objects, it is therefore necessary by means of suitable heat treatment to impart to the article, besides one certain absolutely essential quality, properties desirable and necessary in other respects, which should be the subject of tests for acceptance,

just as structural steel is tested for tensile strength, ductility, contraction, or impact resistance, the values of which are often incorporated in specifications.

Frequently the selection of steel for tools and other hardened articles is based on empirical methods, and sometimes the only demand is that the steel shall acquire sufficient hardness on being hardened. More thorough investigations with regard to the mechanical properties of hardened steel are not usually undertaken, but modern conditions of work appear to call for systematic tests of such steel in order that for a certain purpose suitable steel and suitable treatment may be employed. Very often the only tests used are cutting tests pure and simple, which are tedious and apt sometimes to mislead the judgment.

The following properties, important in tool steel, have been determined in the present series of tests :

(*a*) Limit of elasticity, limit of proportionality, ultimate strength, &c., by means of bending tests.

(*b*) Toughness, or resistance to shock, by means of impact tests.

(*c*) Hardness, by means of indentation tests.

(*a*) The *bending tests* were carried out in a machine designed by Mr. O. Åqvist, Director of Messrs. Stridsberg and Björck, Trollhättan, for the purpose of finding suitable kinds of steel and methods of treatment for the manufacture of saws and knives at the works of that firm. The machine was manufactured by the A.B. Alpha, Stockholm, and its construction and method of working will be seen from the diagram (Fig. 1). The test-piece had a cross-section of $1 \cdot 5 \times 5$ millimetres. These small dimensions were chosen partly in order that, in hardening, uniform cooling conditions should, as far as possible, prevail right through, so as to obtain the same structure in all parts of the sample, and partly for ease in taking test-pieces from hardened objects.

The test-piece *A* was laid upon two fixed supports *B* and *C*, 20 millimetres apart, and was deflected in the middle by means of a knife-edge *D*, which, through the two bars *E* and the two knife-edges *F* connected therewith, was loaded by pushing forward the movable weight *G* on the lever *H*, the latter being provided with a scale so that the load on the test-piece could be read off

on it. The movable weight was moved by a screw-bar actuated by a motor, whereby the test-piece was automatically loaded with a gradually increasing load and unloaded through the device *K*. Unloading took place after every increase of load of 4 kilogrammes. When fracture occurred the current was automatically cut off and the advance of the weight ceased.

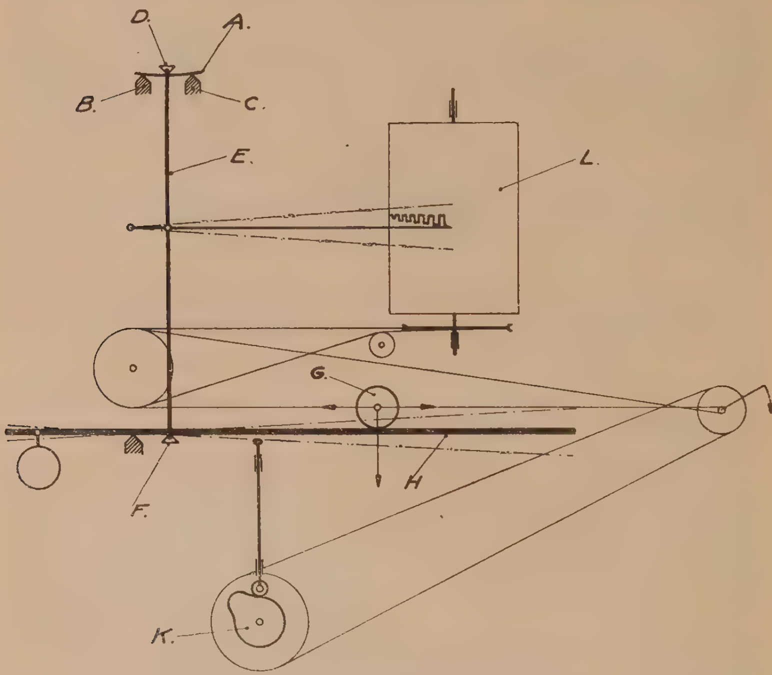

FIG. 1.—Diagram of the Bending Test Machine.

On the cylinder *L* the deformation due to loading and unloading was graphically recorded on a ten-times enlarged scale, the amount of the load being proportional to the movement of the diagram cylinder (1 kilogramme = 1 millimetre). As an example Fig. 2 shows an actual diagram given by a steel with 1·0 per cent. carbon hardened and tempered at 150°, 200°, and 350° C. The tests occupied five to fifteen minutes, after which the limits of proportionality and elasticity, the ultimate stress, and deflection could be read off on the diagram.

In this investigation the load causing a permanent deflection of 0·01 millimetre has been taken as the elastic limit.

The proportional limit is the load at which the deflections cease to be proportional to the loads.

The ultimate strength is understood to be the load at fracture, or, in the case of tough specimens, the maximum load reached.

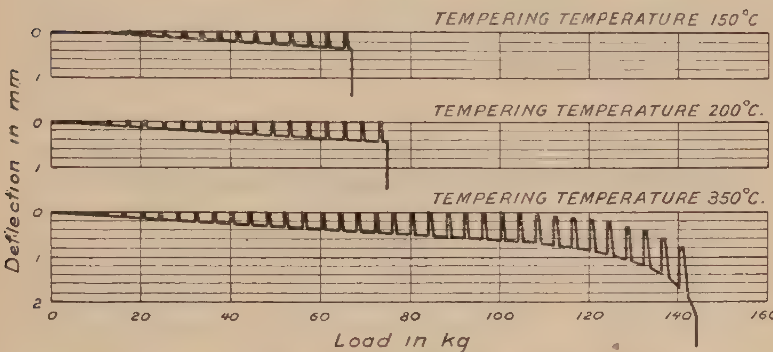

FIG. 2.—Diagram of a Steel with 1·0 per cent. Carbon hardened at 760°, tempered at 150°, 200°, and 350° C.

The ultimate stress is calculated by the formula $\sigma = \frac{M}{W}$, where

σ = stress in kilogrammes per square millimetre ;
M = bending moment ;
W = section modulus.

The same formula is also used in the case of permanent deflection.

(*b*) The *impact tests* were carried out with a Charpy pendulum hammer—height of drop, 0·5 metre ; striking energy, 0·5 kilogramme-metre. The cross-section of the test-pieces was the same as in the bending test, 1·5 × 5 millimetres. The distance between the supports was 20 millimetres.

(*c*) The *tests for hardness* were carried out according to the Rockwell method by means of a diamond cone.

Preparation of Specimens.—The dimensions of the test-pieces were 1·5 × 5 × 80 millimetres ; they were polished with emery-paper, finally with Hubert 1F. The edges were rounded off to

a radius of about 0·05 millimetre, and the finished test-pieces were subjected to the intended heat treatment, hardening, and tempering.

Hardening.—The heating for hardening took place in an electric furnace (Fig. 3). The test-pieces were placed in a stand made of Monel metal, in which six test-pieces could be carried at the same time. This arrangement ensured that all the pieces were subjected simultaneously to the same treatment. During the heating operation the stand was placed in the furnace

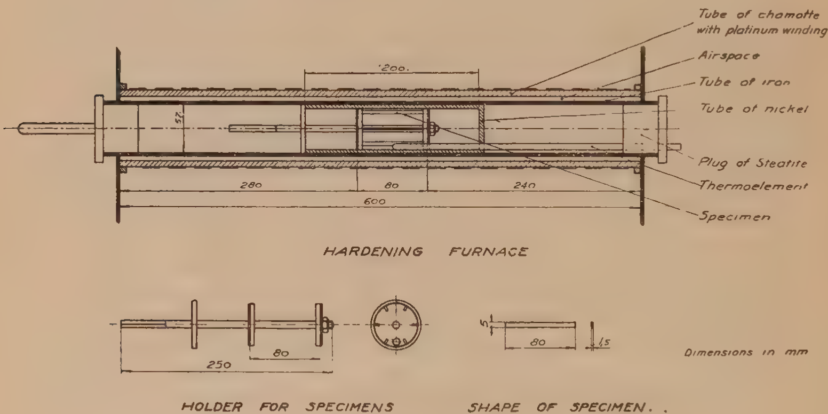

FIG. 3.—Details of the Hardening Furnace.

in such a position that the centre of the specimens was about 3 centimetres beyond the centre of the furnace (reckoned from the mouth of the tube), which was done for the purpose of counteracting the cooling effect of that end of the tube. The furnace was so regulated that the entire period of heating lasted fourteen minutes. The period for reaching the intended quenching temperature was 4 minutes $\pm \frac{1}{2}$ minute.

Quenching was performed in oil at 80° C. After quenching the test-pieces were allowed to remain in the oil for five minutes, after which tempering took place.

The *tempering* was done in oil at temperatures up to 300° C., and in lead at temperatures commencing with 350° C. The period for tempering was ten minutes, during which the temperature could be maintained within $\pm$ 3° C. During this operation the

test-pieces were kept in constant motion, and afterwards were cooled in air while in motion. To ascertain the influence of different cooling methods on the test results a special investigation was performed.

After tempering, some of the test-pieces were polished with emery-paper Hubert 1F, and others were subjected to tests direct without any further polishing. Unless otherwise stated hereafter, the test-pieces were not polished after tempering.

The values obtained for the various properties by means of the above testing methods may be regarded as mutually comparable, and refer to a usual form of testing and method of preparation. With some other method of testing and other shape of specimen other values, also mutually comparable, might possibly be obtained.

II. The Influence of Various Methods of Annealing, and of the Resulting Microstructures, on the Mechanical Properties of the Steel after Hardening.

Material Tested.—Two kinds of simple carbon steel were used for the test, numbered 1 and 2, with the following analyses :

Steel.	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	1·30	0·22	0·37	0·018	0·010
2	1·03	0·23	0·33	0·019	0·012

The steel pieces were rolled into sheet of a thickness of 2·2 millimetres. Some of the test-pieces were, prior to the preparation and hardening, subjected to various methods of annealing, the sheets being first pickled and packed in pig-iron filings to avoid decarburisation during annealing. Annealing was carried out in an electric furnace, and the following methods of annealing were made use of :

A.—No annealing, the specimen being left in the rolled, untreated condition.

B.—Annealing at 745° C., with subsequent cooling at the rate of 10° C. per hour.

C.—Annealing at 720° C. (below Ac1) for twelve hours, with subsequent cooling at the rate of about 30° C. per hour.

D.—Annealing at 760° C., with subsequent cooling at the rate of 10° C. per hour.

E.—Annealing at 820° C., with subsequent cooling at the rate of 60° C. per hour.

F.—Annealing at 850° C., with subsequent cooling at the rate of 60° C. per hour.

Results of Test.

Steel No. 1. *Carbon,* 1·30 *per Cent.*—The structural appearance of the steel after annealing by the different methods, *A*, *B*, *C*, *D*, *E*, and *F*, will be seen from the micrographs, Figs. 19 to 26 (Plates XIV. and XV.).

In the unannealed specimen (*A*) (Fig. 19 before hardening, and Fig. 20 after hardening), the excess cementite appears as a fine network.

In the specimens annealed by methods *B*, *C*, *D*, and *E* (Figs. 21 to 24), the cementite occurs in a spheroidised condition. Method *E* produced the coarsest cementite, *C* the finest grained, and *B* somewhat finer than *D*. The difference in the size of the cementite grains in the specimens annealed according to *B*, *C*, and *D* is relatively slight.

Annealing method *F* caused the development of the excess cementite into coarse grains in network formation (Fig. 25 before hardening, Fig. 26 after hardening).

The specimens were quenched from 755° C. to 760° C. and tempered at 150°, 200°, 300°, and 350° C.

Bending Tests.—In the case of some specimens tempered to the highest temperature no fractures occurred during the bending test. As ultimate stress for such, there is indicated in the diagram the load at which a great downward bend (= about 3 millimetres) suddenly occurs. The curves corresponding with these values are marked with dashes.

The results are summarised in Table I. and in the curves in Fig. 4. From the results will be seen, *inter alia,* the following :

Of the annealing methods, *B*, *C*, and *D*, in an average of several tests, *C* appears to have produced the highest ultimate strength

and D the lowest. No marked difference in the ultimate stress as between these annealing methods is, however, apparent. In the table and curves only the results from material annealed by method B have been included out of those from the B, C, and D methods.

The specimens with the cementite in a more fine-grained

TABLE I.—*Steel No.* 1. *Quenching Temperature*, 755° *to* 760° *C.*

Bending Tests.

Annealing Treatment.	Tempering Temperature. ° C.	Number of Tests.	Bending Strength. Ultimate Stress. Kg./mm.². Average.
B	150	4	181
E	,,	,,	167
A	,,	,,	203
F	,,	2	135
B	200	4	235
E	,,	,,	194
A	,,	,,	213
F	,,	2	186
B	300	4	381
E	,,	,,	297
A	,,	,,	311
F	,,	2	227
B	350	4	381
E	,,	,,	351
A	,,	,,	389
F	,,	2	286

condition (annealing method B) have a higher ultimate stress than those with a more coarse-grained cementite (annealing method E).

Unannealed specimens, A, have after tempering at 200° C. and 300° C. a lower ultimate stress than specimens annealed according to B. Tempered at 150° C., the unannealed specimens, A, possess a higher ultimate stress than the annealed B. At 350° C. tempering, A and B have about the same ultimate stress.

Specimens with the surplus cementite in coarse grains in network formation (annealing method F) have at all tempering temperatures a considerably lower ultimate stress than specimens with the cementite in a granular, spheroidised condition (B and E),

and specimens with finer network of cementite (unannealed specimen *A*).

By raising the tempering temperature from 150° C. to 200° C. the unannealed specimens, *A*, show a less increase of the ultimate stress than the annealed ones. Specimens *B* obtain their

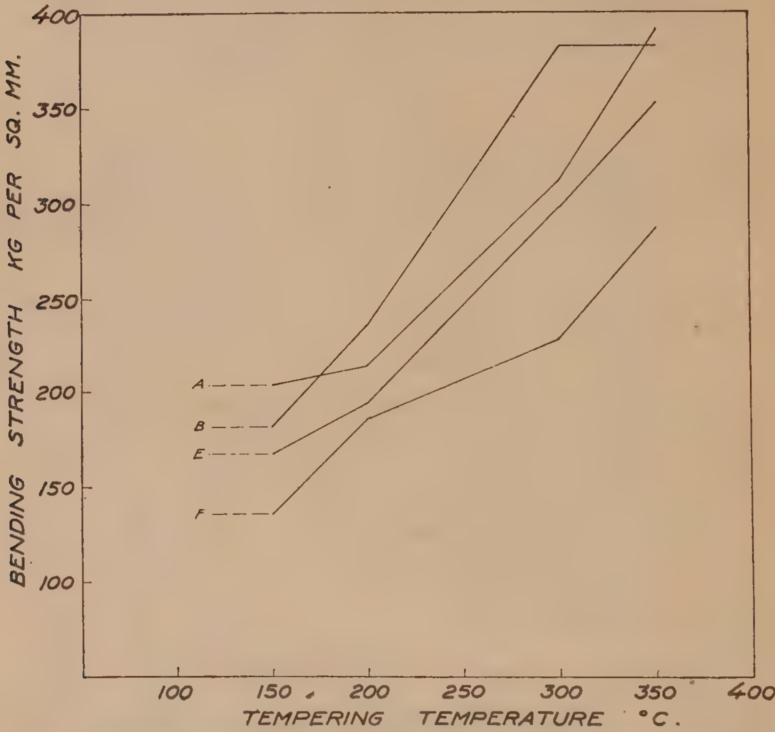

Fig. 4.—Bending Test. Steel No. 1. Hardening Temperature 755°–760° C.

highest ultimate stress by tempering to 300° C. to 350° C., and no increase of the ultimate stress occurs by raising the tempering temperature beyond that point. In the other specimens, *A*, *E*, and *F*, the ultimate stress is considerably increased by raising the tempering temperature from 300° C. to 350° C.

Impact Tests.—The results are summarised in Table II. and in the graph Fig. 5. From the results will be seen, *inter alia*, the following :

For the untempered specimens and those tempered at 150° C. and 200° C. fairly even values have been obtained for the various specimens treated in the same manner. At a tempering temperature of 300° C. and above, on the other hand, great variations

Table II.—*Steel No.* 1. *Quenching Temperature*, 755° *to* 760° *C.*

Impact Tests.

Annealing Treatment.	Tempering Temperature. ° C.	Number of Tests.	Impact Resistance. Kg.cm./mm.². Average.
C	80	4	0·55
B	,,	,,	0·55
D	,,	,,	0·46
E	,,	,,	0·42
A	,,	,,	0·55
F	,,	,,	0·27
C	150	5	0·81
B	,,	,,	0·78
D	,,	,,	0·71
E	,,	,,	0·65
A	,,	,,	0·83
F	,,	,,	0·42
C	200	10	1·24
B	,,	,,	1·15
D	,,	,,	1·09
E	,,	,,	0·92
A	,,	,,	1·06
F	,,	6	0·43
C	300	10	2·8
B	,,	,,	2·9
D	,,	,,	2·8
E	,,	,,	1·8
A	,,	,,	2·3
F	,,	,,	0·53
F	350	6	0·95

have resulted, for which reason no safe judgment as to the relation between the various methods of treatment at this tempering temperature was obtained. The values of impact resistance at 300° C. are the average values for ten tests. In an untempered condition (80° C.) the specimens *A*, *B*, and *C* have the same and highest resistance to impact, after which there come *D*, *E*, and *F* in the order named. At 150° C. tempering, specimens *A*, *B*, and *C*

have the highest and approximately the same impact resistance. From the average figures obtained, *A* is very slightly above *C*, and *C* somewhat above *B*. Thereafter come specimens *D*, *E*, and *F* in the order named.

At 200° C. tempering, *C*, *B*, *D*, and *A* have the highest and fairly equal impact resistance. The average figures for *C*, *B*, *D*,

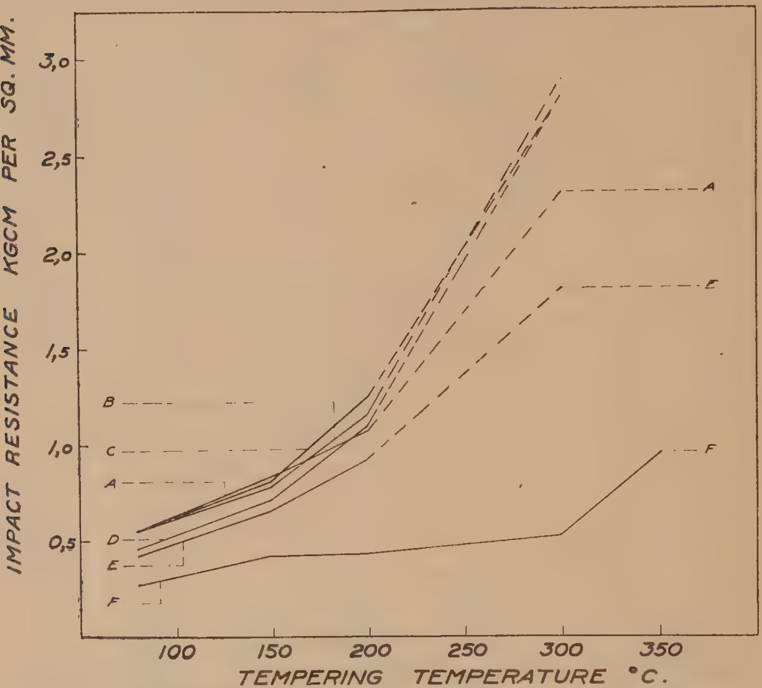

Fig. 5.—Impact Test. Steel No. 1. Hardening Temperature 755°–760° C.

and *A* show that *C* attained the highest and *A* the lowest. *E* and *F* have lower values than the others, *F* being lower than *E*. At 300° C. tempering, the specimens *A*, *E*, and *F* have considerably lower impact resistance than the specimens *B*, *C*, and *D*.

At all the tempering temperatures, specimens with fine-grained cementite have therefore a higher impact resistance than specimens with a coarser-grained cementite or with a coarse network of surplus cementite. Unannealed specimens with a fine network of surplus cementite have, in an untempered condition and

a condition as tempered at 150° C., about the same impact resistance as specimens with fine-grained cementite.

By tempering at 150° C. from an untempered condition (80° C.) the impact resistance in all specimens is increased about

TABLE III.—*Steel No. 2. Quenching Temperature, 755° to 760° C.*

Bending Tests.

Annealing Treatment.	Tempering Temperature. ° C.	Number of Tests.	Bending Strength.		Bending Strength. Ultimate Stress. Kg./mm.². Average.
			Total Kilogrammes.	Average Kilogrammes.	
B	80	2	51–51	51	138
E	,,	,,	38–36	37	100
F	,,	,,	37–35	36	97
B	150	,,	63–64	64	173
E	,,	,,	48–51	49	132
F	,,	,,	48–48	48	130
B	200	,,	72–73	73	197
E	,,	,,	50–54	52	140
F	,,	,,	47–49	48	130
B	300	,,	140–140	140	378
E	,,	,,	83–83	83	224
F	,,	,,	75–70	73	197
B	350	,,	139–143	141	381 [1]
E	,,	,,	105–105	105	284
F	,,	,,	98–98	98	265
B	400	,,	135–135	135	365 [1]
E	,,	,,	117–114	116	313
F	,,	,,	100–105	103	278
B	450	,,	115–114	115	310 [1]
E	,,	,,	105–109	107	289
F	,,	,,	92–90	91	246

[1] Not fractured.

equally. By raising the tempering temperature from 150° C. to 200° C. the specimens *B*, *C*, and *D* increased most in strength, and after them *E*, *A*, and *F* in the order named.

The specimens *F* with a coarse network of surplus cementite possess at all tempering temperatures considerably less impact resistance than the other specimens.

Specimen *F* has, on tempering at 300° C., about the same impact resistance as the specimens *A*, *B*, and *C* in an untempered condition.

Steel No. 2. Carbon, 1·03 per Cent.—The steel was annealed

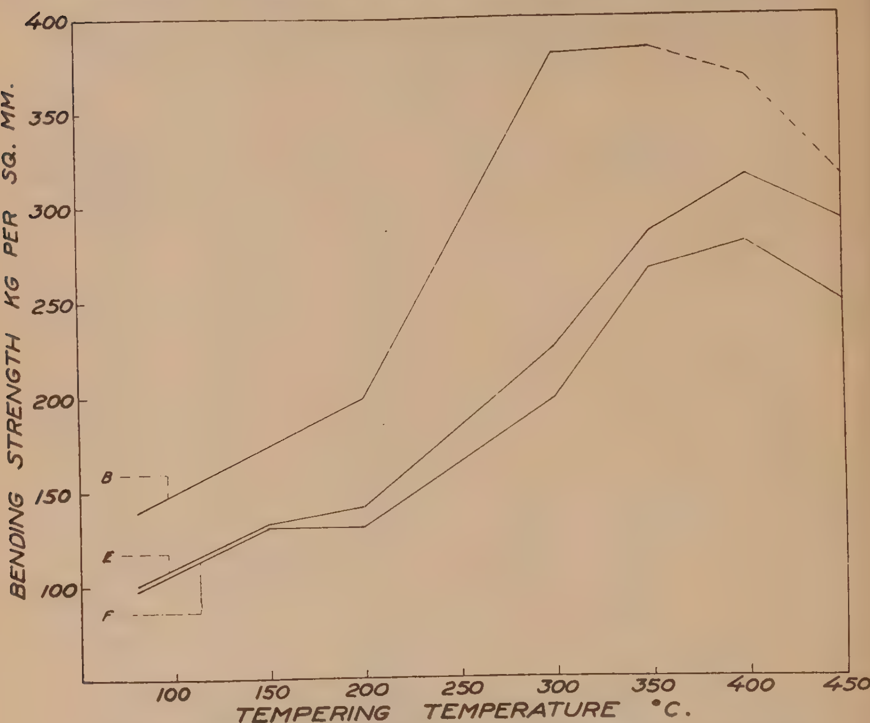

Fig. 6.—Bending Test. Steel No. 2. Hardening Temperature 755°–760° C.

according to the methods *B*, *E*, and *F*. The structural appearance of the steel after annealing by the various methods will be seen by reference to Figs. 27, 28, and 29 (Plate XV.). Specimen *B*, Fig. 27, has fine-grained cementite. Specimens *E*, Fig. 28, and *F*, Fig. 29, have a coarse network of surplus cementite, *F* being coarser than *E*. Fig. 30 shows the specimen *F* after hardening.

The specimens annealed by methods *C* and *D* have also been tested, but relatively slight differences in structural appearance and no marked difference between these and specimen *B* were obtained, for which reason the results of these are not included.

The specimens were quenched from 755° C. to 760° C. and tempered to 150°, 200°, 300°, 350°, 400°, and 450° C.

Bending Tests.—The results are summarised in Table III., and

TABLE IV.—*Steel No. 2. Quenching Temperature, 755° to 760° C.*

Impact Tests.

Annealing Treatment.	Tempering Temperature. ° C.	Number of Tests.	Angle of Rise.		Impact Resistance. Kg.cm./mm.². Average.
			Degrees.	Average Degrees.	
B	80	4	73·2, 73·9, 74·2, 73·2	73·6	0·45
E	,,	,,	74·7, 74·9, 74·8, 75·0	74·9	0·26
F	,,	,,	75·0, 75·0, 75·0, 75·1	75·0	0·24
B	150	,,	71·8, 72·0, 70·7, 70·0	71·1	0·81
E	,,	,,	74·0, 74·0, 73·8, 74·1	74·0	0·39
F	,,	,,	74·7, 74·3, 74·6, 74·4	74·5	0·31
B	200	,,	69·3, 70·0, 69·5, 70·1	69·7	1·00
E	,,	,,	73·6, 74·3, 74·2, 74·0	74·0	0·39
F	,,	,,	74·2, 74·7, 74·8, 74·1	74·5	0·31
B	260	,,	65·0, 62·6, 64·0, 65·8	64·4	1·75
E	,,	,,	73·9, 73·9, 73·8, 73·8	73·9	0·40
F	,,	,,	73·8, 74·0, 73·9, 74·5	74·1	0·37
B	300	,,	44·6, 47·0, 45·7, 45·8	45·8	4·05
E	,,	,,	73·4, 72·6, 72·9, 73·1	73·0	0·53
F	,,	,,	73·4, 74·0, 73·9, 73·8	73·8	0·42
B	350	,,	38·0, 40·4, 27·0, 30·0	33·9	5·20
E	,,	,,	71·6, 71·0, 70·9, 70·8	71·1	0·81
F	,,	,,	70·9, 72·4, 72·9, 73·0	72·3	0·64
B	400	,,	Not fractured	...	Over 5
E	,,	,,	68·7, 66·6, 66·0, 67·0	67·2	1·36
F	,,	,,	70·2, 69·2, 70·9, 70·3	70·2	0·93
B	450	,,	Not fractured	...	Over 5
E	,,	,,	62·4, 65·8, 64·6, 63·6	64·1	1·80
F	,,	,,	69·0, 69·0, 68·6, 69·4	69·0	1·09

the curves are presented in Fig. 6. From the results the following will be seen :

Specimens annealed according to method *B* possess at all tempering temperatures a considerably higher ultimate stress than specimens *E* and *F*. Annealing method *E* produces a somewhat higher ultimate stress than *F*, especially when tempering

at 200° C. and upwards. Specimen *B* attains the highest ultimate stress by tempering at 300° to 350° C., at which temperatures approximately the same ultimate stress is obtained. Specimens *E* and *F* do not reach the highest ultimate stress until tempered at 400° C. In specimen *B* no fracture occurred when tempered to

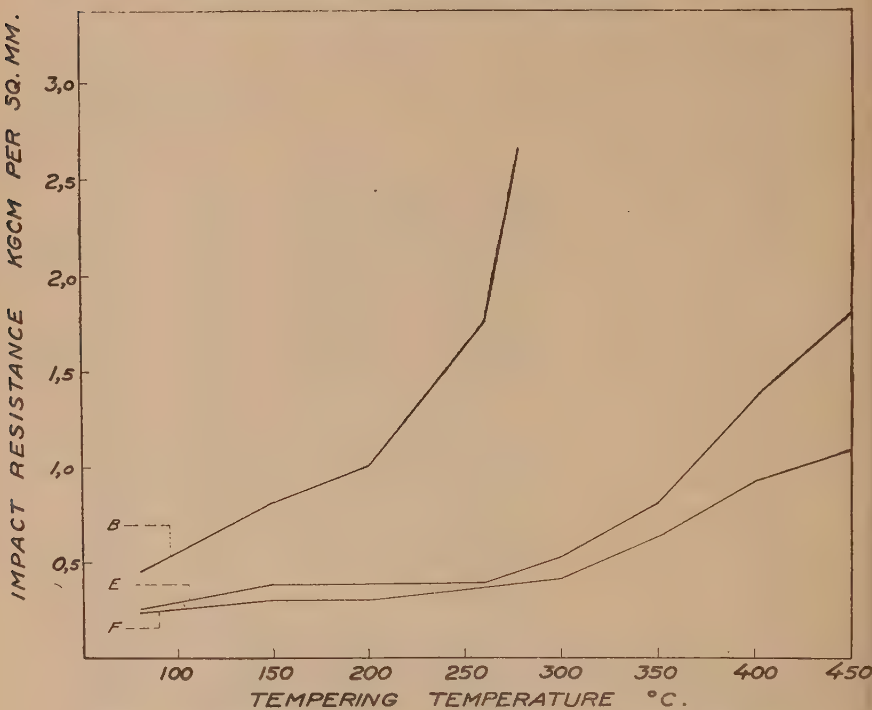

Fig. 7.—Impact Test. Steel No. 2. Hardening Temperature 755°–760° C.

a temperature of 350° C. and beyond; in specimens *E* and *F* fractures occurred at all tempering temperatures. By tempering to 150° C. (from untempered, 80° C.) the ultimate stress in all specimens is increased about equally. By raising the tempering temperature from 150° C. to 200° C. the ultimate stress in specimen *B* is increased considerably more than in specimens *E* and *F*.

Impact Tests.—The results are summarised in Table IV. and in the curves in Fig. 7.

Specimen B gives at all tempering temperatures a very much higher impact resistance than E and F, and specimen E a somewhat higher value than specimen F. When tempering at temperatures of from 300° C. to 450° C. the difference in impact resistance between E and F is greater than when tempering at a temperature below 300° C.

Specimens E and F have their impact resistance very slightly increased by tempering at a temperature below 300° C.; by tempering at 300° C. they have about the same impact resistance as specimen B in an untempered condition.

III. The Influence of Hardening and Tempering Temperature upon the Mechanical Properties of the Steel.

For this investigation four kinds of steel were used, marked Nos. 1, 2, 3, and 4, and having the following analyses:

Steel.	Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	1·30	0·22	0·37	0·018	0·010
2	1·03	0·23	0·33	0·019	0·012
3	0·91	0·09	0·26	0·029	0·012
4	0·59	0·05	0·31	0·028	0·022

Steels Nos. 1 and 2 are the same steels as those used in the previously described tests of Section II. They were tested partly in a rolled unannealed condition, A, and partly annealed according to method B, as specified above—namely, annealing at 745° C. with subsequent cooling at the rate of 10° per hour. Steels Nos. 3 and 4 were subjected to annealing at 800° C. with subsequent free cooling in the air before preparation of the specimens.

All the different kinds of steel were rolled into sheets of a thickness of 2·2 millimetres as in Section II.

The hardening temperatures used were 765°, 790°, and 815° C., and the tempering temperatures were 150°, 200°, 280°, 350°, and 400° C.

The influence on the mechanical properties of the various rates of cooling after tempering was investigated.

Bending Test.—The results are summarised in Table V. and in the curves in Figs. 8, 9, and 10.

TABLE V.—*Steels Nos.* 1 *to* 4.

Bending Tests.

Steel No.	Annealing Treatment.	Tempering Temperature. °C.	Bending Strength. Ultimate Stress. Kg./mm.². Average of about Three Tests.		
			Quenching Temperature, 765° C.	Quenching Temperature, 790° C.	Quenching Temperature, 815° C.
1	*A*	150	197	146	97
1	*B*	,,	192	154	122
2	*A*	,,	157	113	92
2	*B*	,,	173	146	111
3	...	,,	113	95	70
4	...	,,	132	122	122
1	*A*	200	216	178	162
1	*B*	,,	240	235	227
2	*A*	,,	176	157	154
2	*B*	,,	200	194	192
3	...	,,	146	132	127
4	...	,,	194	189	189
1	*A*	280	267	265	205
1	*B*	,,	361	365	311
2	*A*	,,	251	227	211
2	*B*	,,	351	351	284
3	...	,,	203	203	181
4	...	,,	373	378	362
1	*A*	350	381	394	394
1	*B*	,,	375	386	378
2	*A*	,,	383	389	394
2	*B*	,,	378	375	370
3	...	,,	375	354	351
4	...	,,	324 [1]	335 [1]	324 [1]
1	*A*	400	340	351	365
1	*B*	,,	329	335	340
2	*A*	,,	340 [1]	343 [1]	338 [1]
2	*B*	,,	329 [1]	335 [1]	332 [1]
3	...	,,	329	338	324
4	...	,,	286 [1]	286 [1]	278 [1]

[1] Not fractured.

Steel 1 in the annealed condition *B* has, with the quenching temperatures used, and tempered at 150° and 200° C., a higher

ultimate stress than the other kinds of steel (with certain exceptions).

Steels 1 and 2 in the annealed condition *B* give, with all quenching temperatures and tempering at 150° to 280° C., considerably higher ultimate stresses than the unannealed ones, with the exception of those quenched from 765° C. and tempered at

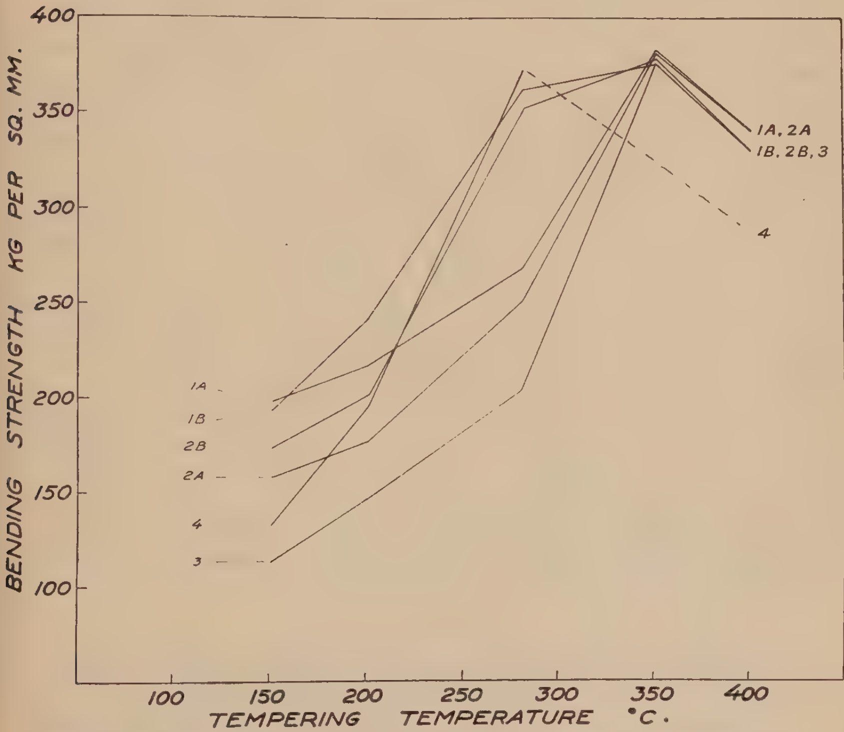

FIG. 8.—Bending Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 765° C.

150° C., where the unannealed (*A*) and annealed (*B*) specimens of steel 1 possess about the same ultimate stress.

Steel 3 possesses, with the quenching temperatures used and tempered at 150° to 280° C., a lower ultimate stress than the other kinds of steel.

Steel 4 possesses, at all hardening temperatures and tempered at 280° C., a higher ultimate stress than the others.

With 350° C. and 400° C. tempering, there occurs at all three hardening temperatures slight differences in the ultimate stress of the steels 1, 2, and 3, steel 3 having a somewhat lower ultimate stress than the others, and the unannealed specimens *A* of steels 1 and 2 giving a slightly higher ultimate stress than the annealed

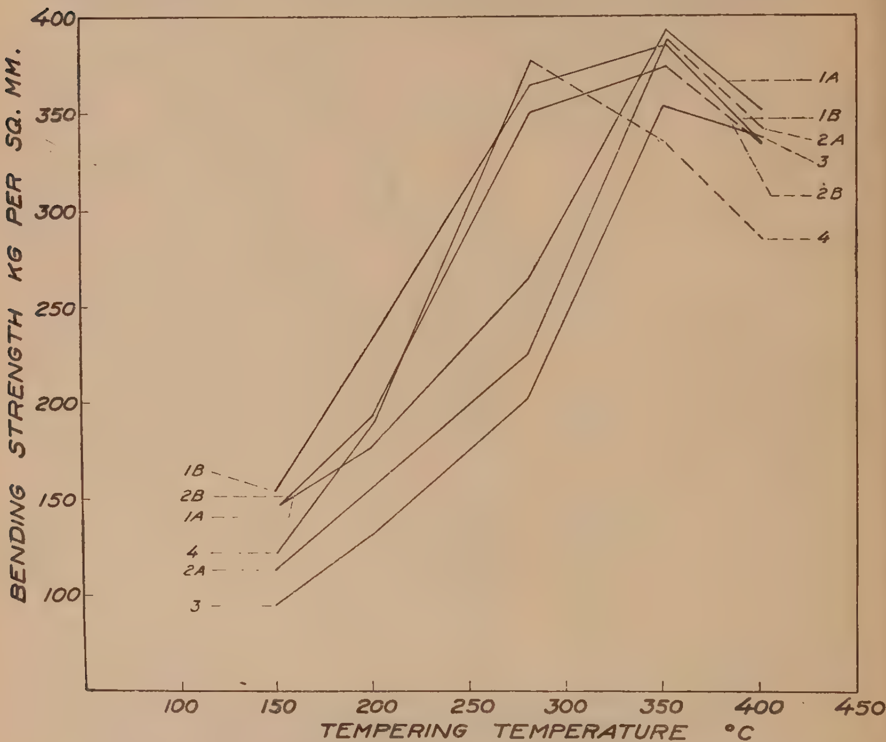

Fig. 9.—Bending Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 790° C.

ones. This difference between the various kinds of steel increases somewhat as the quenching temperature increases.

By raising the tempering temperature from 150° to 280° C. the annealed specimens of steels 1 and 2 attain at all quenching temperatures a considerably greater increase in ultimate stress than the unannealed ones.

By raising the tempering temperature from 280° to 350° C., after quenching from 765° and 790° C., the unannealed speci-

mens A of steels 1 and 2 show a considerably greater increase in ultimate stress than the specimens with B annealing.

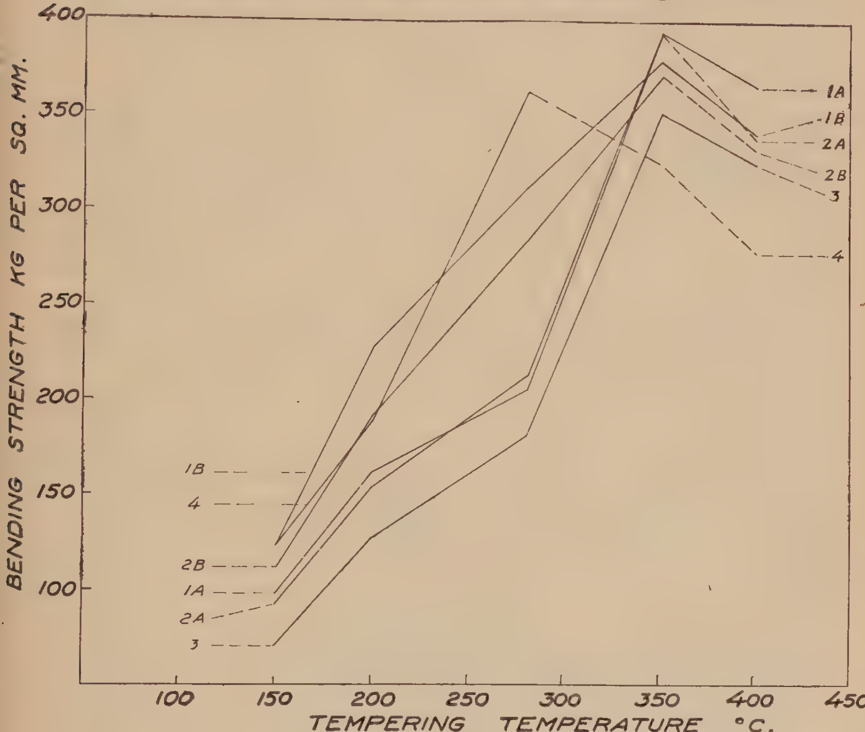

FIG. 10.—Bending Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 815° C.

Relation between Ultimate Stress in Bending, Hardening Temperature, and Tempering Temperature. Curves, Fig. 11.

Tempering Temperature, 150° *C.*—In all the steels the ultimate stress drops as the quenching temperature is raised.

When the quenching temperature is raised from 765° to 790° C. the unannealed specimens A of steels 1 and 2 display a greater diminution in ultimate stress than the others.

By raising the quenching temperature from 765° to 815° C., specimen A of steel 1 shows the greatest decrease in ultimate stress. Of all the steels No. 4 shows the smallest decrease in ultimate stress.

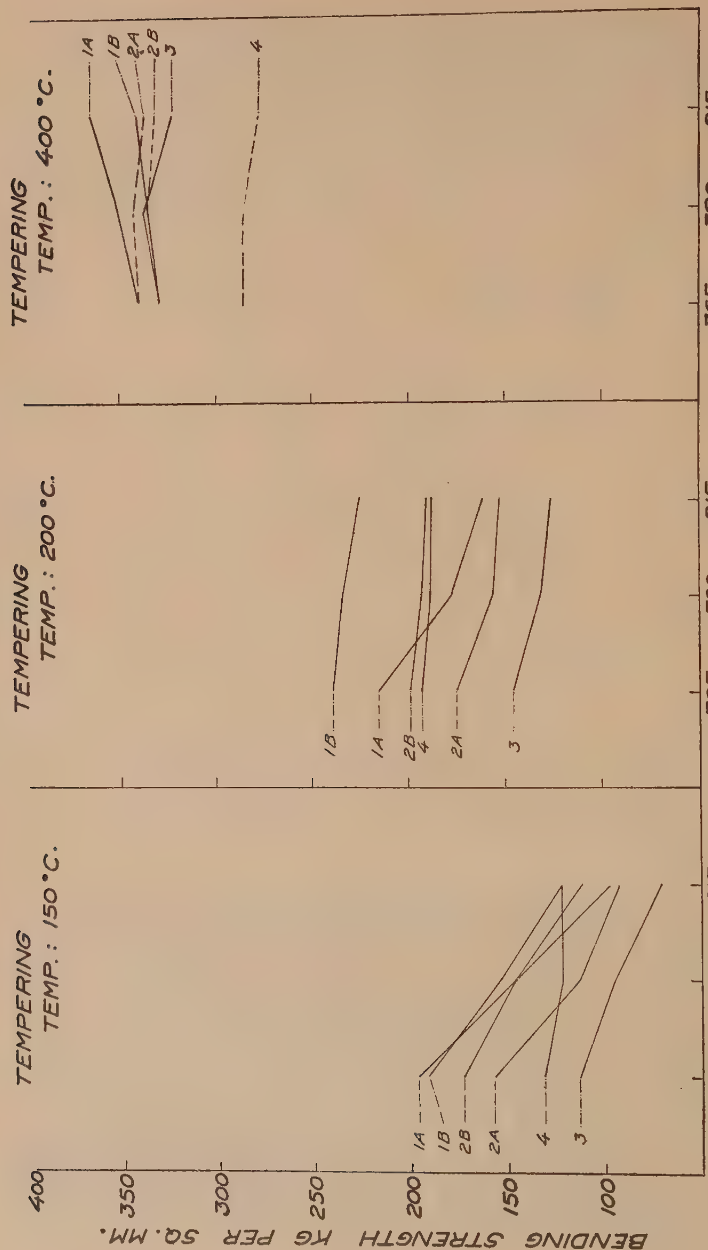

FIG. 11.—Bending Test. Steels Nos. 1, 2, 3, and 4. Relation between Bending Strength, Hardening Temperature, and Tempering Temperature.

Tempering Temperature, 200° *C.*—All the steels tempered at 200° C. show a smaller reduction in ultimate stress due to raising

TABLE VI.—*Steels Nos.* 1 *to* 4. *Quenching Temperatures*, 765°, 790°, *and* 815° *C.*

Bending Tests.

Steel No.	Annealing Treatment.	Quenching Temperature, ° C.	Tempering Temperature, ° C.	Proportional Limit. Kg. mm.² Approx.	Elastic Limit. Kg./mm.². Approx.	Deflection in Millimetres when Loaded. 100 Kg.	110 Kg.	120 Kg.	Permanent Deflection in Millimetres after Unloading. 100 Kg.	110 Kg.	120 Kg.
1	*A*	765	350	250	270	0·60	0·71	0·87	...	0·06	0·14
1	*B*	,,	,,	250	250	0·60	0·71	0·86	0·02	0·06	0·17
2	*A*	,,	,,	250	260	0·60	0·71	0·86	0·03	0·05	0·16
2	*B*	,,	,,	240	250	0·62	0·70	0·92	0·03	0·07	0·20
3	...	,,	,,	250	250	0·62	0·70	0·90	0·03	0·06	0·19
4	...	,,	,,	215	215	0·71	1·13	...	0·18	0·44	...
1	*A*	765	400	240	260	0·65	0·81	1·20	0·04	0·10	0·40
1	*B*	,,	,,	210	230	0·79	1·20	...	0·16	0·42	...
2	*A*	,,	,,	240	250	0·67	0·90	1·40	0·05	0·30	0·65
2	*B*	,,	,,	230	230	0·71	1·00	2·20	0·16	0·35	0·85
3	...	,,	,,	215	230	0·70	1·04	2·10	0·12	0·36	0·96
4	...	,,	,,	195	215	1·34	...	...	0·69	...	...
1	*A*	790	350	260	260	0·58	0·70	0·81	0·02	0·05	0·12
1	*B*	,,	,,	255	260	0·62	0·77	0·81	0·02	0·05	0·13
2	*A*	,,	,,	245	255	0·59	0·67	0·83	0·02	0·07	0·15
2	*B*	,,	,,	240	250	0·62	0·78	0·97	0·05	0·09	0·22
3	...	,,	,,	235	235	0·70	0·87	1·16	0·10	0·10	0·40
4	...	,,	,,	210	210	0·77	1·05	1·95	0·16	0·40	1·10
1	*A*	790	400	230	250	0·62	0·83	1·15	0·06	0·16	0·46
1	*B*	,,	,,	230	230	0·70	0·95	1·57	0·11	0·27	0·72
2	*A*	,,	,,	215	225	0·70	0·98	1·70	0·14	0·32	0·84
2	*B*	,,	,,	220	220	0·70	0·98	1·70	0·14	0·32	0·90
3	...	,,	,,	210	210	0·79	1·20	2·16	0·23	0·46	1·40
4	...	,,	,,	190	190	1·70	...	...	0·96	...	...
1	*A*	815	350	250	290	0·58	0·68	0·83	...	0·03	0·09
1	*B*	,,	,,	240	285	0·58	0·69	0·84	...	0·05	0·14
2	*A*	,,	,,	250	285	0·59	0·65	0·82	...	0·04	0·14
2	*B*	,,	,,	240	260	0·59	0·73	0·94	0·03	0·08	0·22
3	...	,,	,,	235	255	0·60	0·73	1·02	0·05	0·11	0·29
4	...	,,	,,	215	240	0·70	1·03	...	0·13	0·38	...
1	*A*	815	400	240	250	0·67	0·77	1·13	0·05	0·16	0·31
1	*B*	,,	,,	215	240	0·68	0·91	1·68	0·12	0·31	0·80
2	*A*	,,	,,	205	215	0·70	0·96	1·88	0·16	0·36	0·97
2	*B*	,,	,,	195	215	0·79	1·21	2·60	0·18	0·48	1·49
3	...	,,	,,	200	220	0·82	1·26	...	0·21	0·58	...
4	...	,,	,,	190	200	1·70	...	...	0·92	...	...

the quenching temperature than those tempered at 150° C. The annealed specimens *B* of steels Nos. 1 and 2 show a less reduction in ultimate stress than the unannealed *A*.

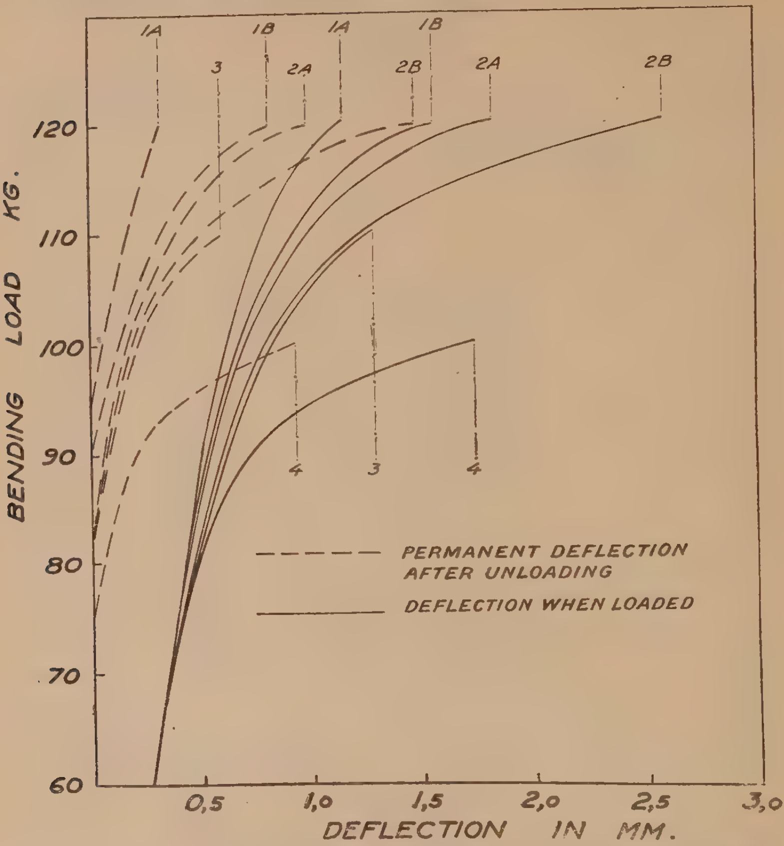

FIG. 12.—Bending Diagrams. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 815° C. Tempering Temperature 400° C.

Steel 1 (*A*) shows the greatest reduction and steel 4 the smallest.

Tempering Temperature, 400° *C*.—Steel 1, in both *A* and *B* conditions, shows a somewhat increased ultimate stress, due to raising the quenching temperature from 765° to 815° C. The other steels show about the same ultimate stress with quenching temperatures of 765° and 815° C.

The limits of proportionality and elasticity and the deflection on loading and unloading, after tempering at 350° and 400° C., are summarised in Table VI. From this it will be seen that approximately the same limits of proportionality and elasticity

TABLE VII.—*Steels Nos.* 1 *to* 4.

Impact Tests.

Steel No.	Annealing Treatment.	Tempering Temperature. ° C.	Impact Resistance. Kg.cm./mm.². Average of about Six Tests.		
			Quenching Temperature, 765° C.	Quenching Temperature, 790° C.	Quenching Temperature, 815° C.
1	*A*	150	0·71	0·53	0·22
1	*B*	,,	0·73	0·52	0·42
2	*A*	,,	0·47	0·33	0·24
2	*B*	,,	0·65	0·45	0·34
3	...	,,	0·33	0·21	0·17
4	...	,,	0·62	0·49	0·46
1	*A*	200	0·88	0·58	0·36
1	*B*	,,	1·05	0·93	0·49
2	*A*	,,	0·67	0·53	0·36
2	*B*	,,	0·90	0·87	0·52
3	...	,,	0·53	0·31	0·31
4	...	,,	1·44	1·04	0·93
1	*A*	280	2·7	1·2	0·52
1	*B*	,,	2·8	2·4	1·08
2	*A*	,,	1·7	1·1	0·50
2	*B*	,,	3·4	2·1	1·03
3	...	,,	0·9	0·43	0·38

are obtained with the various quenching temperatures at one and the same tempering temperature. By raising the tempering temperature from 350° to 400° C. the limits of proportionality and elasticity drop.

With regard to the deflections the following may be mentioned as worthy of note. The unannealed specimens *A* of steels 1 and 2 show a smaller deflection both on loading and after unloading than the annealed specimens *B*. Steel 3 shows a greater deflection than steels 1 and 2, and steel 4 a greater deflection than steel 3, with the same loads beyond the limits of elasticity and proportionality.

In Fig. 12 are plotted the curves of the deflection which

occurred on loading and after unloading in all the kinds of steel quenched from 815° C. and tempered at 400° C.

Impact Tests.—The results are summarised in Table VII. and in curves in Figs. 13, 14, and 15.

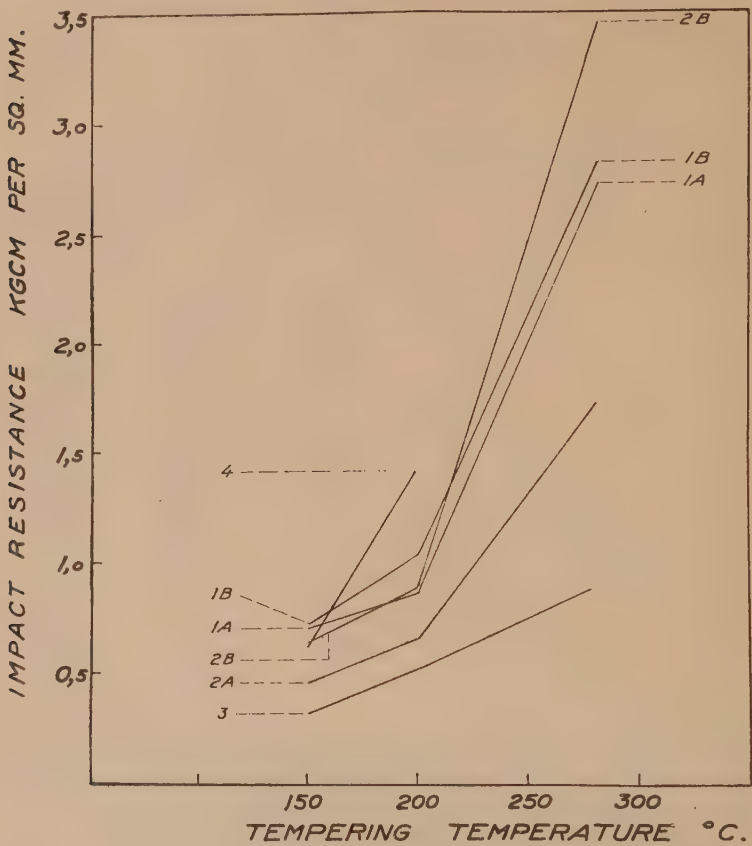

FIG. 13.—Impact Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 765° C.

With each of the quenching temperatures 765° and 790° C. and tempering at 150° C., the steels 1 (*A*), 1 (*B*), 2 (*B*), and 4 possess about the same resistance to impact, and higher than the remaining steels 2 (*A*) and 3. Of these 2 (*A*) is higher than 3. With tempering at 200° C. and over, steel 4 possesses at all quenching temperatures a higher impact resistance than the

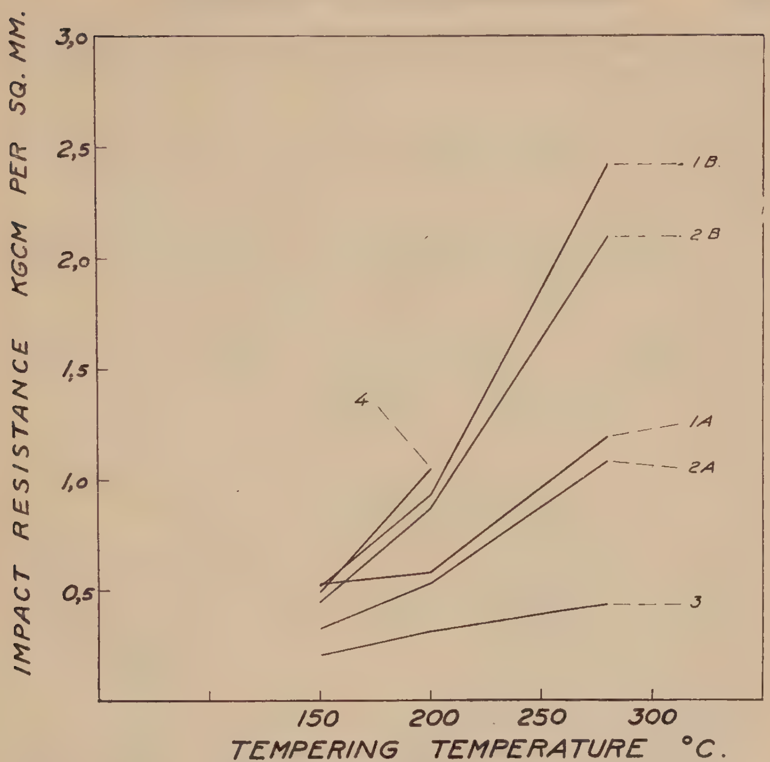

FIG. 14.—Impact Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 790° C.

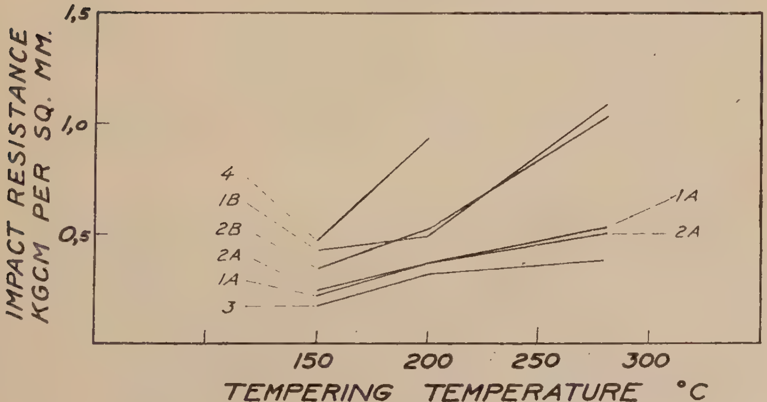

FIG. 15.—Impact Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 815° C.

remaining steels. Steel 3 possesses, at all quenching temperatures, and tempering at 150° and 280° C., a lower impact resistance than the others.

When tempering at 150° to 280° C., the annealed specimens *B* of steels 1 and 2 possess higher impact resistances than the unannealed *A*.

By raising the tempering temperature from 150° to 280° C., the annealed specimens *B* of steels 1 and 2 have their impact resistance increased more than the unannealed *A*.

By raising the tempering temperature from 150° to 280° C., steel 4 shows the greatest increase in impact resistance at all quenching temperatures, and steel 3 the smallest.

Relation between Impact Resistance, Hardening Temperature, and Tempering Temperature. Curves, Fig. 16.

Tempering Temperature, 150° *C.*—On increasing the quenching temperature the impact resistance of all the steels is reduced.

Steel 1 in unannealed condition *A* has its impact resistance reduced more than the others.

The impact resistance of steel 4 is reduced least of all by raising the quenching temperature.

Tempering Temperature, 200° *C.*—In all the steels there occurs a greater drop in the impact resistance by raising the quenching temperature than with tempering at 150° C.

Steel 3 has its impact resistance reduced least of all by raising the quenching temperature from 765° to 815° C. The same steel has, however, at each of the quenching temperatures used, a considerably lower impact resistance than all the others. Steel 3 has, with a quenching temperature of 765° C., a lower impact resistance than that which steel 2 (*B*), for example, possesses on quenching from 815° C.

Tempering Temperature, 280° *C.*—In all the steels tempered at 280° a greater drop in the impact resistance is produced by raising the quenching temperature from 765° to 815° C. than in those tempered at 150° and 200° C. and quenched under the same conditions. Steel 3 is again the one which shows with this tempering (at 280°) the least drop in impact resistance, due to raising the quenching temperature.

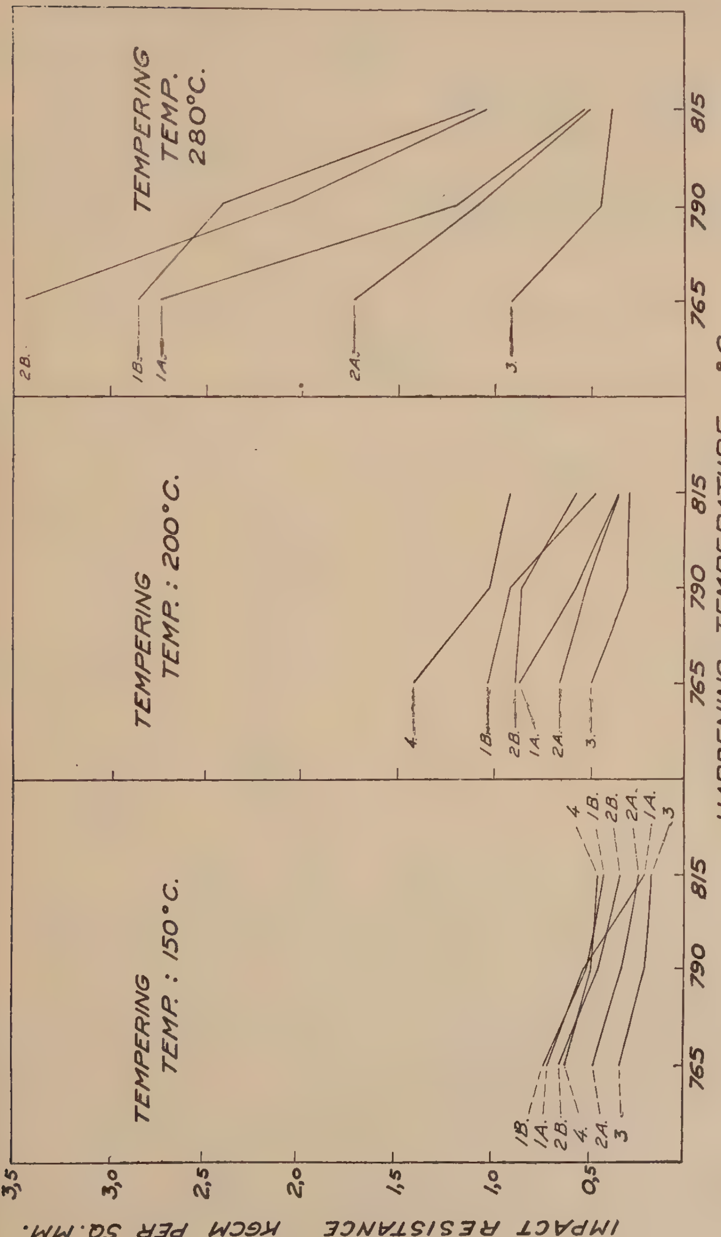

FIG. 16.—Impact Test. Steels Nos. 1, 2, 3, and 4. Relation between Impact Resistance, Hardening Temperature, and Tempering Temperature.

By raising the quenching temperature from 765° to 815° C. there occurs, at all tempering temperatures, the greatest drop per cent. in steel 1 (*A*), and the least drop per cent. in steel 4 (150° and 200° C. tempering).

As previously mentioned, very irregular values were obtained at the higher tempering temperatures for the different specimens, subjected to similar treatment, for which reason it is impossible to draw a definite conclusion from these results. Nevertheless,

TABLE VIII.—*Steels Nos.* 1 *to* 4. *Quenching Temperature,* 765° *C.*

Impact Tests.

Comparison between specimens polished after hardening and unpolished specimens.

Steel No.	Annealing Treatment.	Tempering Temperature. °C.	Impact Resistance. Kg.cm./mm.².	
			Polished.	Unpolished.
1	*A*	150	0·87	0·71
1	*B*	,,	0·88	0·73
2	*A*	,,	0·62	0·47
2	*B*	,,	0·74	0·65
3	...	,,	0·36	0·33
4	...	,,	0·63	0·62
1	*A*	200	1·20	0·88
1	*B*	,,	1·44	1·05
2	*A*	,,	0·96	0·67
2	*B*	,,	1·40	0·90
3	...	,,	0·53	0·53
4	...	,,	1·50	1·44

it is apparent that the effect of the quenching temperature on the impact resistance, at higher tempering temperatures, is considerably less than in the case of the lower tempering temperatures. Some of the results appear to indicate that in some steels the same and even a greater impact resistance is obtained at a quenching temperature of 815° C. than at one of 765° C.

After tempering, some of the specimens were polished with emery-paper Hubert 1F before testing, and compared with specimens not polished after tempering. In this connection, in the bending tests, no difference in ultimate stress could be observed; while, on the other hand, in the impact tests with specimens

tempered at 150° and 200° C. throughout, a slightly greater impact resistance was obtained for the specimens that had been polished after tempering (see Table VIII.).

Hardness Tests.—The results of hardness tests carried out with steel hardened at 765° C. are summarised in Table IX. and in the curves of Fig. 17.

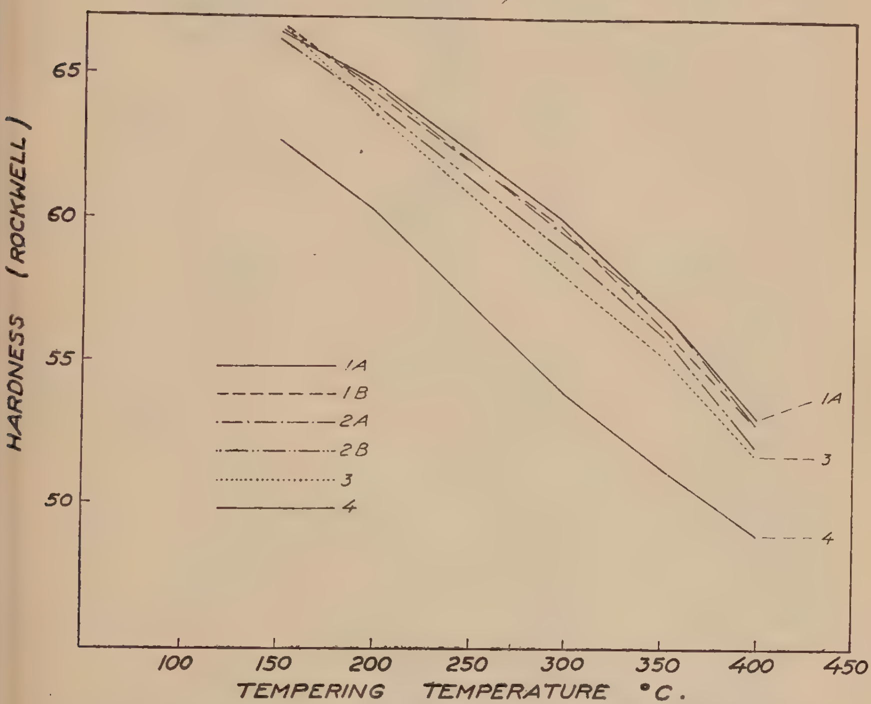

FIG. 17.—Hardness Test. Steels Nos. 1, 2, 3, and 4. Hardening Temperature 765° C.

The average figures of several tests show that with one and the same tempering temperature (at 200° C. and over) steel 1 (*A*) shows the greatest hardness of all those tested, after which, in descending degree, come 1 (*B*), 2 (*A*), these two being almost alike, 2 (*B*), 3 and 4, in the order named. The unannealed specimens of steels 1 and 2 thus appear, after hardening, to have a somewhat greater hardness than the annealed ones. There is comparatively little difference between steels 1, 2, and 3, whereas, between these,

on the one hand, and steel 4, on the other, there is a considerable drop in hardness.

TABLE IX.—*Steels Nos.* 1 *to* 4. *Quenching Temperature*, 765° *C.*
Hardness Tests (*Rockwell*).

Steel No.	Annealing Treatment.	Tempering Temperature. ° C.	Hardness (Rockwell). Average of about Ten Tests.
1	*A*	150	66·5
1	*B*	,,	66·8
2	*A*	,,	66·6
2	*B*	,,	66·2
3	...	,,	66·7
4	...	,,	62·7
1	*A*	200	64·7
1	*B*	,,	64·4
2	*A*	,,	64·6
2	*B*	,,	64·0
3	...	,,	63·9
4	...	,,	60·3
1	*A*	300	59·9
1	*B*	,,	59·6
2	*A*	,,	59·5
2	*B*	,,	58·9
3	...	,,	58·0
4	...	,,	53·8
1	*A*	350	56·8
1	*B*	,,	56·3
2	*A*	,,	56·8
2	*B*	,,	56·0
3	...	,,	55·3
4	...	,,	51·3
1	*A*	400	53·0
1	*B*	,,	52·8
2	*A*	,,	52·8
2	*B*	,,	52·0
3	...	,,	51·8
4	...	,,	49·0

Relation between Ultimate Stress in Bending, Impact Resistance, and Hardness in Steels 1 (*B*), 2 (*B*), 3, *and* 4 ; *see Curves, Fig.* 18.

In the case of hardness numbers (Rockwell) above 55 to 56, steel 1 (*B*) has the highest ultimate stress of all on bending; next to steel 1 (*B*) comes steel 2 (*B*). The difference in ultimate stress between the two steels is greatest when the hardness is

greatest, and decreases when the hardness decreases. With a hardness of about 57 to 55 the two steels show the same ultimate

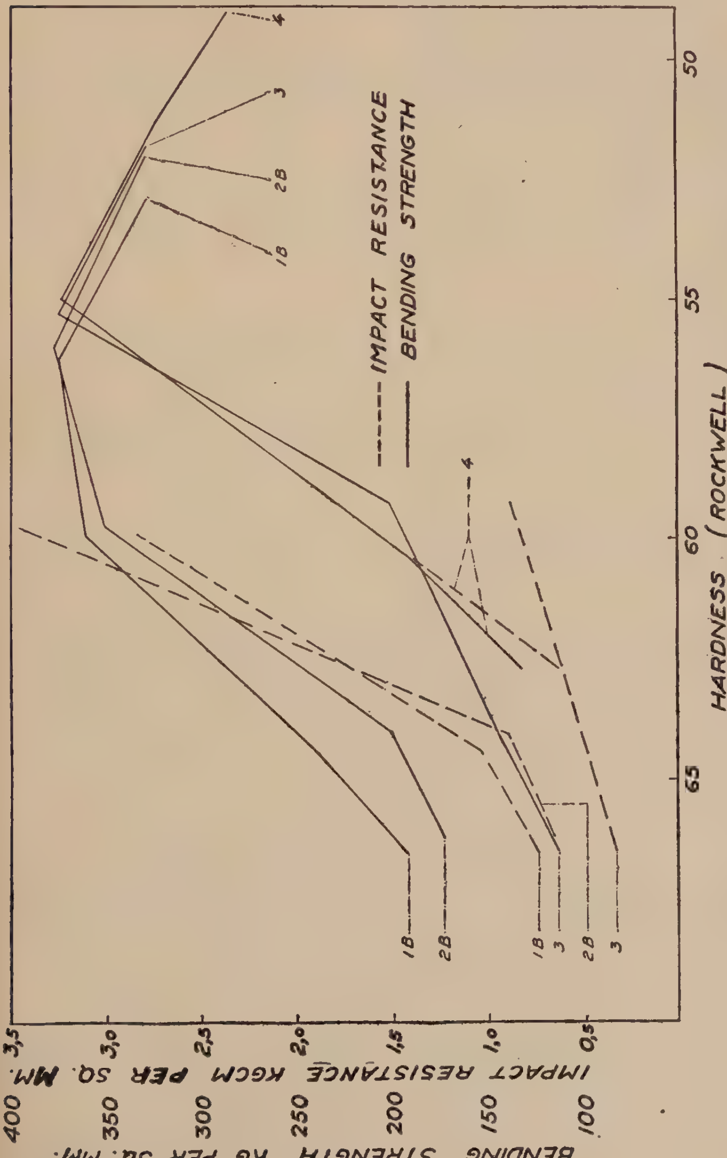

Fig. 18.—Steels Nos. 1 (B), 2 (B), 3 and 4. Hardening Temperature 765° C. Relation between Hardness, Bending Strength, and Impact Resistance.

stress. Steels 3 and 4 have, with a hardness above 56, a considerably lower ultimate stress for bending than steels 1 (*B*) and 2 (*B*). With a hardness number of about 55, all the steels show about the same ultimate stress.

With hardness numbers below about 55, the difference in ultimate stress between the various steels is very slight. Steel 1 (*B*) possesses, with the highest hardnesses, a higher impact resistance than the other steels.

With the hardness number of about 62, steels 1 (*B*) and 2 (*B*) show the same impact resistance, and with a hardness figure between 62 and 60, 2 (*B*) possesses a higher impact resistance than the other steels.

With a hardness number of about 63, steels 3 and 4 possess the same impact resistance; with reduced hardness, steel 4 shows a greater impact resistance than steel 3.

Effect on the Bending Strength of the Rate of Cooling after Tempering.

In carrying out some of the series of tests it was found that, with tempering temperatures of 250° and 300° C., very irregular values were obtained for various specimens, which had to all appearance been treated in the same manner. On a closer observation it was found that the rate of cooling after tempering greatly influenced the results of the bending tests. For this reason an investigation was made of the influence exercised by two different methods of cooling upon the ultimate stress in the bending tests. The cooling methods used were:

(*a*) Cooling in the air immediately above the tempering furnace, where the temperature was about 30° to 40° C.

(*b*) Immediately after tempering the specimens were plunged into benzene and allowed to cool completely whilst being stirred. By the dissolution of the oil in the benzene very rapid cooling took place.

In the tests of both Sections II. and III., the specimens, after tempering, were cooled in air at about 18° C., while in motion, producing a rate of cooling lying between (*a*) and (*b*).

The results obtained by the cooling methods (*a*) and (*b*) are given in Table X., from which it is apparent that the more rapid

TABLE X.—*Influence on the Bending Strength of Rate of Cooling after Tempering. Steels Nos. 1 to 4. Quenching Temperature, 765° C. Tempering Temperature, 300° C.*

Steel No.	Annealing Treatment.	Cooled in Benzene from Tempering Temperature. Bending Strength, Total Kilogrammes. Average of Four Tests.	Cooled in Air from Tempering Temperature. Bending Strength, Total Kilogrammes. Average of Four Tests.
1	*A*	103	151
1	*B*	108	156
2	*A*	86	138
2	*B*	102	154
3	...	80	140
4	...	122	137

cooling in benzene produces considerably lower ultimate stresses throughout than the slower air-cooling process. The greatest difference on an average occurred with steel 3, and the smallest with steel 4.

This remarkable state of things will be more thoroughly investigated at different tempering temperatures.

SUMMARY.

For testing the mechanical properties of hardened steel in those respects which are important for the practical use of steel, there has been elaborated a testing system, including bending tests, determination of limits of proportionality, elasticity, and ultimate strength, as well as impact and hardness tests.

Four kinds of carbon steel with 1·3, 1·0, 0·9, and 0·6 per cent. carbon have been subjected to comparative tests after hardening and tempering at various temperatures.

Two of the steels, with carbon 1·3 and 1·0 per cent., were, prior to hardening, also subjected to various annealing treatments for bringing about various structural forms.

From the series of tests carried out results were obtained, of which some are already known from practical experience. Others, however, have been obtained which might be difficult and tedious to discover definitely merely by practical tests.

Of the results obtained the following may be specially referred to:

1. The steels with 1·3 and 1·0 per cent. of carbon respectively, annealed in such a manner that the cementite was developed in a fine-grained form, show, with subsequent hardening and tempering, a higher bending strength and a higher impact resistance than specimens which, before hardening, have been annealed so that more coarse-grained cementite has developed.

Specimens in which all the cementite is spheroidised show, after hardening, higher bending strength and impact resistance than those which have a coarse network of surplus cementite.

Specimens with a finer network of surplus cementite show a higher bending strength and impact resistance than specimens with a coarser network.

2. Steel with the highest percentage of carbon of those tested (carbon, 1·3 per cent.), using the three quenching temperatures 765°, 790°, and 810° C. and tempering at 150° and 200° C., shows a higher bending strength than the other steels tested.

Steel with carbon 0·9 per cent., at all quenching temperatures and with tempering up to 280° C., shows the lowest bending strength of all the steels tested.

Specimens of steel with carbon 1·3 and 1·0 per cent., after annealing so that fine-grained cementite has developed (annealing method *B*) show, at all hardening temperatures and tempering temperatures (with a certain exception) up to 280° C., a higher bending strength than the unannealed ones.

With increased quenching temperature all the steels tempered at 150° and 200° C. show a reduced bending strength. This is the case in a higher degree with steels tempered at 150° than with those tempered at 200° C.

With increased tempering temperature the steels become, with regard to bending strength, less susceptible to the raising of the quenching temperature. With tempering at 400° C. an increase of the quenching temperature from 765° to 815° C. has very little effect.

3. Steel with 1·3 per cent. carbon at low tempering temperatures, 150° and 200° C., has on an average a somewhat higher impact resistance than a steel with 1·0 per cent. carbon. Steel with 0·6 per cent. carbon possesses, at all quenching temperatures used, and 150° C. tempering, approximately the same impact resistance as the steel with 1·3 per cent. carbon. With 200° C.

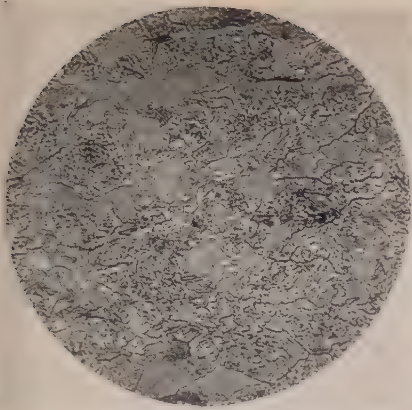

FIG. 19.—Steel No. 1. Unannealed (*A*), before hardening.

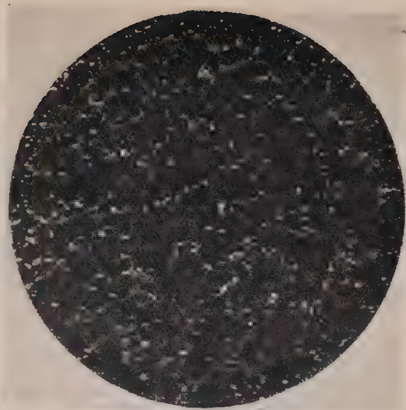

FIG. 20.—Steel No. 1. Unannealed (*A*), after hardening.

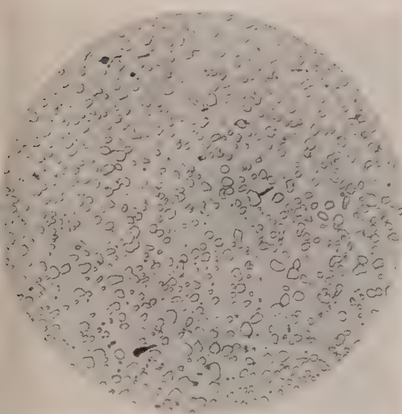

FIG. 21.—Steel No. 1. Annealing treatment *B*.

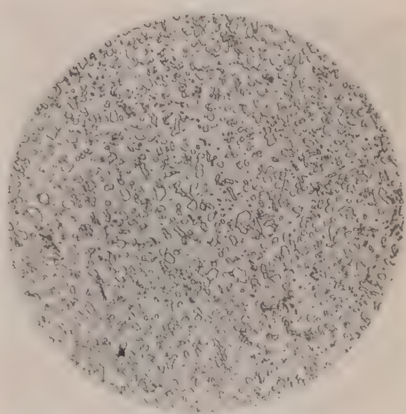

FIG. 22.—Steel No. 1. Annealing treatment *C*.

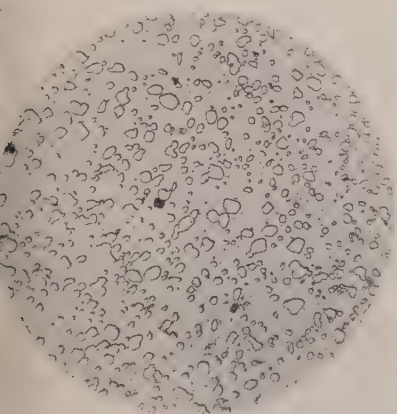

FIG. 23.—Steel No. 1. Annealing treatment *D*.

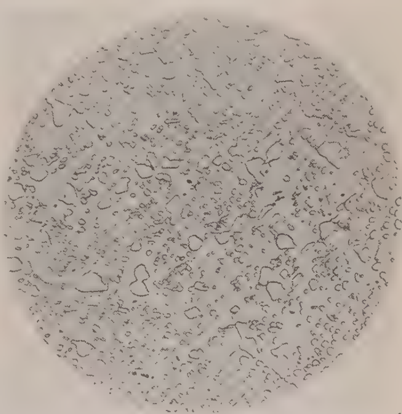

FIG. 24.—Steel No. 1. Annealing treatment *E*.

NOTE.—All the above micrographs were taken at 600 diameters, and are reproduced at four-fifths.

[*To face p.* 260

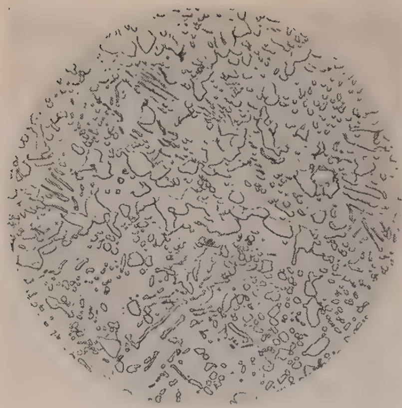

FIG. 25.—Steel No. 1. Annealing treatment F, before hardening.

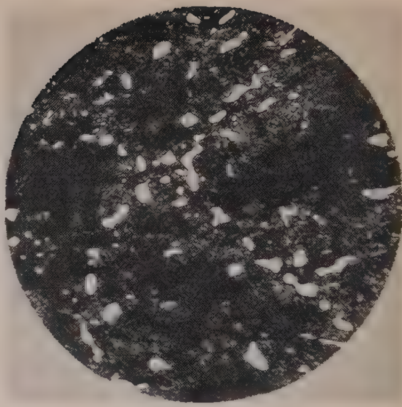

FIG. 26.—Steel No. 1. Annealing treatment F, after hardening.

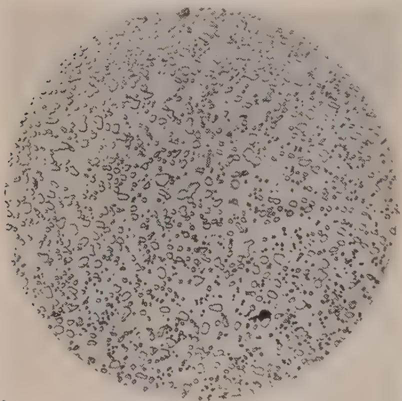

FIG. 27.—Steel No. 2. Annealing treatment B.

FIG. 28.—Steel No. 2. Annealing treatment E.

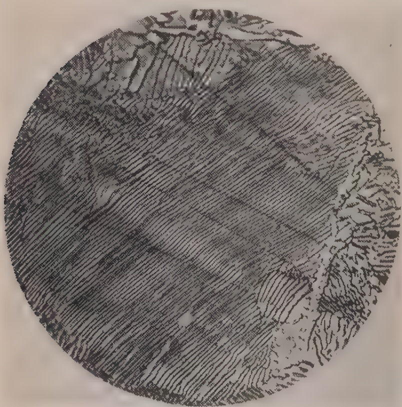

FIG. 29.—Steel No. 2. Annealing treatment F, before hardening.

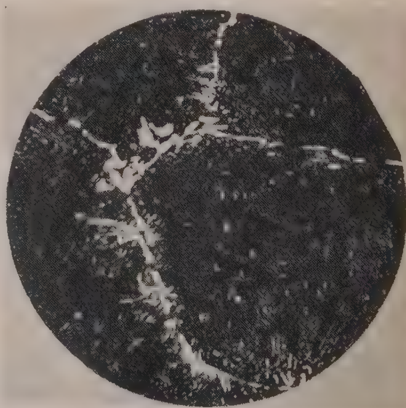

FIG. 30.—Steel No. 2. Annealing treatment F, after hardening.

NOTE.—All the above micrographs were taken at 600 diameters, and are reproduced at four-fifths.

tempering and beyond, steel with 0·6 per cent. carbon possesses a higher impact resistance than the other steels tested.

Steel with 0·9 per cent. carbon has, at all quenching temperatures used and tempering temperatures up to 280° C., a lower impact resistance than all the other steels tested. By raising the quenching temperature the impact resistance is reduced when tempering up to 280° C. With a higher tempering temperature (below 280° C.) a certain increase in the quenching temperature reduces the impact resistance more than in the case of lower tempering.

4. With regard to hardness, a great difference is apparent between, on the one hand, the steels with 1·3, 1·0, and 0·9 per cent. carbon, and, on the other, the steel with 0·6 per cent. carbon, inasmuch as the last mentioned possesses considerably less hardness than the others. Between the three first-mentioned no great difference was obtained. The average figures for several tests nevertheless show the greatest hardness for steel with 1·3 per cent. carbon, and the smallest for steel with 0·9 per cent. carbon. Likewise a slightly greater hardness has been obtained for the specimens unannealed before hardening than for the annealed specimens of steel with 1·3 and 1·0 per cent. carbon.

When examining the relation between hardness, bending strength, and impact resistance at 765° C. quenching temperature, it will be seen that with the highest hardnesses steel with 1·3 per cent. carbon possesses a greater bending strength and impact resistance than the other steels. With lower hardnesses all show approximately the same bending strength. The impact resistance, above a certain hardness, is greatest for steel with 1·3 per cent. carbon, after which steel with 1·0 per cent. carbon possesses the greatest impact resistance up to a certain hardness. For specimens with lower hardness no trustworthy testing results have been obtained.

5. The influence upon the ultimate bending stress of the rate of cooling after tempering has been tested with a tempering temperature of 300° C. In this connection it has been found that, in the case of very rapid cooling in benzene, a much lower bending strength was obtained than in the case of a less rapid cooling in air.

DISCUSSION.

Dr. Arthur Bramley (Loughborough) inquired whether the author had carried out any experiments on the duration of the period of tempering—for instance, tempering at 150° C. for ten minutes, twenty minutes, an hour, and so on. The last table given in the paper rather suggested that the duration of tempering, as well as the sudden effect of quenching, might have some effect.

Dr. W. H. Hatfield (Sheffield) said that there was no statement in the paper indicating the kind of steel employed; the expression used was that four kinds of steel were employed, meaning four different carbon contents. It would be very interesting, particularly to the Sheffield members, to know by what metallurgical process the steel upon which the author had experimented had been made. It would also be of great value if the work could be extended to steels made by different processes, with the object of ascertaining whether any intrinsic characteristics in the materials, which were not readily disclosed by simple quantitative tests, could be determined. He was quite in accord with the author's statement emphasising the necessity for putting such steels into the globular condition prior to hardening and tempering.

CORRESPONDENCE.

Dr. W. H. Hatfield (Sheffield) wrote in a further communication that to present a paper on the subject demanded not a small amount of courage, for it was generally taken as an axiom that in that branch of the applications of steel the only test of any value was the test of service. While the merits of a hardened article must still be judged by that criterion, the method of attack of the subject adopted by the author was to be highly commended. The particular forms of mechanical tests used were of a specially practical and reasonable nature; it could only have been wished that some form of test for resistance to " wear " could have been included.

There were several points which offered room for criticism. In the comparison of the four steels of varying carbon content, steels 3 and 4, the lower carbon steels, were not strictly comparable with steels 1 and 2, owing to the variations in the other elements. It was particularly in the hardened steels that details of composition might be of serious consequence. It was not easy to see why the definite conclusion should be reached that the 1·3 per cent. carbon steel had a higher bending strength after being tempered at 150° and 200° C. than the lower carbon steels, since the essential difference between the steels at the hardening

temperatures adopted was in the amount of free cementite. Spheroidised cementite would not be expected to have a toughening effect (as against the relative absence of such a constituent), and it should be worth while considering another possibility. Two samples of steel might be imagined, both having their excess cementite in a completely spheroidised form, but one having the particles relatively large and widely scattered, the other having them small and well distributed. If a comparison were made between Fig. 21 of the 1·3 per cent. carbon steel and Fig. 27 of the 1·03 per cent. carbon steel, it was not obvious where the difference of carbon was to be found, but as the particles in the former were larger than those in the latter, their somewhat wider spacing was partially accounted for.

The size and distribution of the cementite particles depended not only on the particular annealing treatment, but also on the condition of the material prior to annealing. A bar which was forged and then cooled from a very high temperature would give, on receiving subsequently a good annealing treatment, a much coarser structure than one forged at a moderate temperature. It would be interesting to know whether that feature had any real bearing on the conclusion given on p. 260; a repetition of the comparison under conditions where the materials before annealing were as nearly identical as possible would be instructive.

The general effects of a cellular structure as against a spheroidal structure were in complete accord with existing ideas, and the effects of various tempering and hardening treatments provided very useful data. There were several directions in which more information was wanting, and he would like to suggest the necessity for more detailed knowledge of the effects of tempering temperatures between 0° and 250° C.

Mr. A. Hultgren (Söderfors, Sweden) wrote that the author introduced his subject by analysing in a general way the combination of properties he considered desirable for some tools chosen as examples. After determining, as he had done in a thorough manner, the various properties investigated, it seemed well worth while, if he could, to co-ordinate those properties with the results of practical tests with tools of different composition and heat-treated in various ways. He (Mr. Hultgren) realised that such service tests would require a great deal of work and would involve the co-operation of other people who were in a position to supervise them on the spot, but he thought the full benefit of the author's investigation would not be obtained until such tests were made. He hoped, therefore, that the author's work would be extended in the direction indicated.

In reply to Dr. Bramley and Dr. Hatfield, Mr. Lundgren observed that the primary purpose of the paper was to give an account of the work carried out at the Government Testing Institute, Stockholm, to

devise a practical method for testing the properties of hardened steel. In order to demonstrate the applicability of the method, series of tests on various carbon steels with different heat-treatments were described. The four steels used were produced in the acid open-hearth according to the normal Swedish methods, steels Nos. 1 and 2 originating from one steelworks, and Nos. 3 and 4 from another; all were hot-rolled to a thickness of 2·2 millimetres, and delivered to the Testing Institute without further heat-treatment.

One series of tests was intended to show the effect of heat-treatment before hardening on the properties of the hardened steel. The results did, in fact, show that if one of two specimens of the same steel, hardened and tempered in identically the same manner, were given, by a special heat-treatment before hardening, coarser cementite grains and a coarser network of the excess cementite, then it offered inferior resistance to bending and shock than the other sample which had finer grains and a finer network.

Those tests were more of a preliminary character. The next series of investigations on the properties of hardened steel, now planned or in progress, were: (A) Determinations of the influence of the period of tempering, and of the rapidity of cooling after tempering; (B) comparative tests on a series of steels with varying carbon content, but otherwise of a composition and with a treatment as similar as possible; (C) comparative tests of steels with various alloys, and produced in different ways.

He quite agreed with Mr. Hultgren that the proposed testing methods must be compared with the results of practical experience. Investigations on certain hardened objects, such as saw blades, plane cutters, &c., in which they would be subjected to tests in the laboratory by the proposed methods and to parallel trials in practice, were therefore being planned. The question of testing them for wear would also be gone into.

In conclusion, he wished to thank those who had taken part in the discussion and correspondence for their kind and valuable contributions.

THE MECHANICAL PROPERTIES OF FOUR HEAT-TREATED SPRING STEELS.*

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(From the National Physical Laboratory.)
(Research carried out for the Engineering Co-ordinating Research Board of the Department of Scientific and Industrial Research.)

Introduction.

The investigation described in this paper has been undertaken at the National Physical Laboratory as part of a systematic investigation of the mechanical properties of steels commonly used in spring manufacture which forms part of the programme of the Springs Committee. The steels investigated are those most frequently used in the manufacture of laminated springs, and the material was therefore obtained mainly in the form of flat plates 3 in. × $\frac{3}{8}$ in. in section. The tests have been devised with a view to disclosing the mechanical properties of the materials, and the test-pieces have been prepared in such a manner as to eliminate, as far as possible, variations due to surface blemishes, decarburisation, or other disturbing factors. At a later stage in the investigation, a determination of the properties of these materials in the form of complete springs will be necessary; in connection with these latter tests, the results described in the present paper are of fundamental importance.

Materials.

The materials consist of two straight carbon steels containing 0·6 and 0·8 per cent. of carbon respectively, a silico-manganese and a chrome-vanadium spring steel, and all are typical high-grade steels supplied by leading firms of steel makers. Tests of two chrome steels and a nickel-chrome steel are in hand or contemplated, as are tests on cold-worked steels of various compositions.

In addition to the 3-in. × $\frac{3}{8}$-in. rolled plates, some of each cast has been supplied as round bar $1\frac{1}{4}$ inch in diameter. Each

* Received July 7, 1926.

material has been supplied from one cast only. The chemical analyses, together with the B.E.S.A. specifications to which they were supplied, are given in Table I.

TABLE I.—*Analyses of Materials.*

		C. %	Si. %	S. %	P. %	Mn. %	Ni. %	Cr. %	V. %
0·6 per cent. carbon steel	3 in. × ⅜ in. plate	0·60	0·21	0·007	0·011	0·77	0·08	0·09	...
	1¼ in. diameter bar	0·60	0·22	0·007	0·012	0·77	0·08	0·12	...
	Specification	0·50 to 0·65	Max. 0·50	Max. 0·06	Max. 0·05	0·60 to 1·00	...	...	...
0·8 per cent. carbon steel	3 in. × ⅜ in. plate	0·82	0·25	0·019	0·026	0·41	...	trace	...
	1¼ in. diameter bar	0·79	0·23	0·016	0·027	0·41	...	trace	...
	Specification	0·75 to 0·90	Max. 0·50	Max. 0·06	Max. 0·05	0·35 to 0·70	...	...	...
Silico-manganese steel	3 in. × ⅜ in. plate	0·54	1·95	0·021	0·021	0·94	...	trace	...
	1¼ in. diameter bar	0·53	2·00	0·022	0·018	0·94	...	trace	...
	Specification	0·50 to 0·60	1·50 to 2·00	Max. 0·06	Max. 0·05	0·60 to 1·00	...	...	...
Chrome-vanadium steel	3 in. × ⅜ in. plate	0·55	0·29	trace	0·006	0·68	0·10	1·16	0·27
	1¼ in. diameter bar	0·53	0·29	trace	trace	0·67	0·10	1·15	0·27
	Specification	0·45 to 0·55	Max. 0·50	Max. 0·06	Max. 0·05	0·50 to 0·80	...	0·80 to 1·20	Min. 0·15

HEAT TREATMENT.

The critical range of each steel has been examined (*a*) by thermal curves, (*b*) by microscopic examination of quenched specimens. In general, thermal curves disclosed the temperatures of Ar1 and Ac1, but did not indicate Ar3 and Ac3. The latter temperature was determined by examining the microstructure of specimens that had been quenched at suitable temperatures, and ascertaining the minimum temperature at which the constituent ferrite was completely removed. From the results of the experiments suitable hardening temperatures were determined. In conjunction with these experiments specimens of each composition, quenched from a suitable temperature into oil or water, were tested in a Brinell machine to ascertain the degree and the uniformity of hardening. As a result of all the above tests a suitable hardening process was determined for each steel.

A series of specimens of plate 3 inches long was then hardened by suitable quenching, and tempered one at each of a series of temperatures extending over the normal tempering range. The Brinell hardness of these tempered specimens was measured, and

from these results suitable tempering temperatures for each steel were determined.

It is clear that if any comprehensive series of mechanical tests is to be made on material in each condition of heat treatment, the investigation becomes extremely large unless the number of heat treatments is limited. In these tests each material has been subjected to the complete series of mechanical tests when drawn to four different tempering temperatures. Considerable care has been taken in fixing the heat treatments in order that a comprehensive series of tests should be available, and the following main principles have been observed in fixing the different temperatures.

For hardening it has been considered desirable to fix such conditions of temperature, quenching medium, &c., as will give a completely martensitic structure possessing as high a Brinell number as possible, but without causing cracks to form during or after quenching. In the tests described this was accomplished successfully, except in the case of the 0·8 per cent. carbon steel, for which no hardening treatment was found that would produce a completely martensitic structure in the test samples without forming cracks. A "toughening" treatment was adopted for this material, as described later.

For tempering, four temperatures were chosen, such as, when applied to hardened material for three minutes, would produce material whose Brinell hardness numbers varied from about 350 to 500—*i.e.* over the range of hardness usually found in laminated springs made from these materials.

(1) 0·6 *per Cent. Carbon Steel.*—On the heating curve A3 was absent; a very slight arrest occurred at 760° C., probably A3A2, and a well-marked arrest, A1, occurred at 729° C. On the cooling curve only one arrest was observed, at 679° C. The quenching experiments showed that incomplete hardening was obtained by quenching in oil from 860° C., and the pieces were not uniform. Eventually specimens were quenched in oil from 950° C., and complete and uniform hardening was obtained.[1] The results of

[1] Numerous devices were tried to obtain uniformly hard specimens with lower quenching temperatures than 950° C., including the preliminary dipping of the hot sample in water, to crack off the scale, before immersion in oil. The same procedure was used in connection with the heat treatment finally adopted, but the authors are not certain that satisfactory results would not have been obtained by direct oil-quenching; subsequent experiments suggest that scale-cracking may not be essential with a quenching temperature of 950° C.

hardness tests on 3-inch pieces quenched in this way and tempered at various temperatures are given in Table II. and Fig. 7.

TABLE II.

3-Inch Pieces Oil-Quenched from 950° *C.*

Tempering temperature, ° C.	...	250	300	350	400	450	500	550	600
Brinell number . . .	590	545	545	490	444	418	369	351	315

From these results it was decided to carry out mechanical tests on the material oil-quenched from 950° C. and tempered at each of the temperatures 400° C., 450° C., 500° C., and 550° C.

The structure of the material as oil-hardened from 950° C. was mainly martensitic, but a little troostite was present; oil-quenching from this temperature was only just sufficiently severe to produce the hardened condition.

A photomicrograph of the material in the hardened and tempered condition is shown in Fig. 9 (Plate XVII.), and demonstrates the effect of tempering at 550° C. No troostite was present.

(2) 0·8 *per Cent. Carbon Steel.*—On each of the thermal curves only one arrest point was found, at 742° C. on the heating curve, and at 712° C. on the cooling curve. This would be expected in a steel so nearly of the eutectoid composition. It was not found possible to harden the steel completely by oil-quenching from 830° C., 900° C., or 950° C., the rate of transformation being very rapid and the oil-quench too slow to suppress the transformation entirely. Hardness tests on 3-inch pieces showed that specimens quenched in oil from 900° C. were fairly uniform at about 370 Brinell number, and that tempering at temperatures lower than 550° C. had little effect. Similar results were obtained by oil-quenching from 830° C., but the pieces were not nearly so uniform throughout as when quenched from 900° C. The results of hardness tests on 3-inch pieces are given in Table III. and Fig. 7.

TABLE III.

3-Inch Pieces Oil-Quenched from 900° *C.*

Tempering temperature, ° C.	...	250	300	350	400	450	500	550	600
Brinell number . . .	364	360	360	375	375	364	375	337	309

From these results it was decided to carry out complete mechanical tests on the material as oil-quenched from 900° C., and tempered at each of the temperatures 500° C. and 550° C., and to make tensile and impact tests on specimens oil-quenched from 830° C. and tempered. The normalised material consisted entirely of pearlite; quenching produced a sorbitic structure which was little affected by tempering.

The photomicrograph (Fig. 10, Plate XVII.) illustrates the quenched material when tempered at 550° C.

(3) *Silico-Manganese Steel.*—On the cooling curve A2 occurred at 700° C. and A1 at 698° C.; on the heating curve, however, the points A1 and A2 were reversed, A2 occurring at 724° C. and A1 at 733° C. The effect of both oil- and water-quenching was determined in the preliminary hardening experiments, and it was found that heating to 870° C. was necessary in order to produce complete solution of the ferrite. As a result of these preliminary experiments a temperature of 870° C. was adopted for water-hardening and 950° C. for oil-hardening. No signs of hardening cracks were seen in either the oil- or water-quenched specimens. The effect of tempering at various temperatures on 3-inch pieces is given in Table IV. and Fig. 7.

TABLE IV.

3-Inch Pieces Oil-Quenched from 950° C.									
Tempering temperature, ° C.	...	250	300	350	400	450	500	550	600
Brinell number . . .	600	566	550	550	540	490	428	372	345
3-Inch Pieces Water-Quenched from 870° C.									
Tempering temperature, ° C.	...	250	300	350	400	450	500	550	600
Brinell number . . .	650	590	575	545	540	500	424	387	336

From these results it was decided to make complete tests on the material when oil-quenched from 950° C. and tempered, and when water-quenched from 870° C. and tempered. The tempering temperatures adopted in both cases were 450° C., 500° C., 550° C., and 600° C.

Fig. 11 (Plate XVII.) shows a typical structure of the oil-hardened material after tempering at 450° C.

(4) *Chrome-Vanadium Steel.*—Three arrest points were found

on both the heating and cooling curves. Ac2 and Ac3 and also Ar3 and Ar2 all occurred at 781° C. Ac1 occurred at 720° C. and Ar1 at 717° C. It was found that oil-quenching from 850° C. produced a martensitic structure and a Brinell number of 640. The effect of tempering at various temperatures on 3-inch pieces is given in Table V. and Fig. 7.

Table V.

3-*Inch Pieces Oil-Quenched from* 850° *C.*

Tempering temperature, ° C.	...	250	300	350	400	450	500	550	600
Brinell number . . .	640	620	578	540	512	477	466	444	400

From these results it was decided to make complete tests on the material when oil-quenched from 850° and tempered at each of the temperatures 400° C., 475° C., 550° C., and 600° C. The microstructures were extremely fine, and a high magnification was necessary in order to show them clearly. Normalised material from 850° C. gave a sorbitic structure, and the material may be regarded as toughened when in this condition. Oil-quenching from 850° C. gave a martensitic structure.

The photomicrograph (Fig. 12, Plate XVII.) shows the effect of tempering the quenched material.

Mechanical Tests.

The following mechanical tests have been carried out on the hardened and tempered materials :

Complete tensile tests.
Rotating cantilever fatigue tests.
Izod impact tests.
Complete torsion tests.

The specimens, or the plates from which the specimens were afterwards prepared, were heated in a gas-fired muffle for the hardening operations. The furnace temperature was raised to 10° above the required quenching temperature ; the steel was then put in, raised to the furnace temperature, and held there for three

minutes before quenching. For the 0·6 per cent. carbon steel the furnace temperature was 30° above the quenching temperature, to allow for cooling during scale-cracking. In the case of the silico-manganese steel, water-quenched, it was found that quenching into cold water tended to produce warped specimens, and water at about 40° C. was used to overcome this defect in the quenching operation.

A nichrome-wound electric furnace was used for the tempering operations. The furnace was held at the desired temperature, the pieces were then put in, and after reaching the tempering temperature were held there for three minutes. This short time was adopted because the temperature of the pieces rose very slowly when they were in the furnace, particularly when approaching the furnace temperature. All the pieces were quenched in cold water after tempering.

Preliminary Tests.

It has been stated that the material was obtained in the form, mainly, of $3 \times \frac{3}{8}$-inch rolled spring section, and it was obviously desirable to prepare the test-pieces from this section in preference to the round bar material. In making fatigue and impact tests on hardened and tempered steel, it is usual to machine the specimens to within 0·02 inch of the finished size from the rolled or normalised material. The hardening and tempering operations are then carried out and the specimens finally ground to the correct finished dimensions. In the present tests, in order to preserve uniformity of treatment for all test-pieces, it was thought desirable to prepare the fatigue and impact specimens from the plate material after heat-treatment. Preparation of specimens in this way entailed rather more labour than was usual in machining operations, and preliminary tests were made in order to see if the extra labour were justified. Fatigue and impact specimens were rough machined from the rolled plates of 0·6 per cent. carbon steel and the silico-manganese steel; they were then hardened and tempered, and finally ground to the finished dimensions shown in Fig. 1. The final grinding to size removed about 0·02 inch of surface material (unless otherwise stated), and the impact specimens were notched after heat treatment. Several

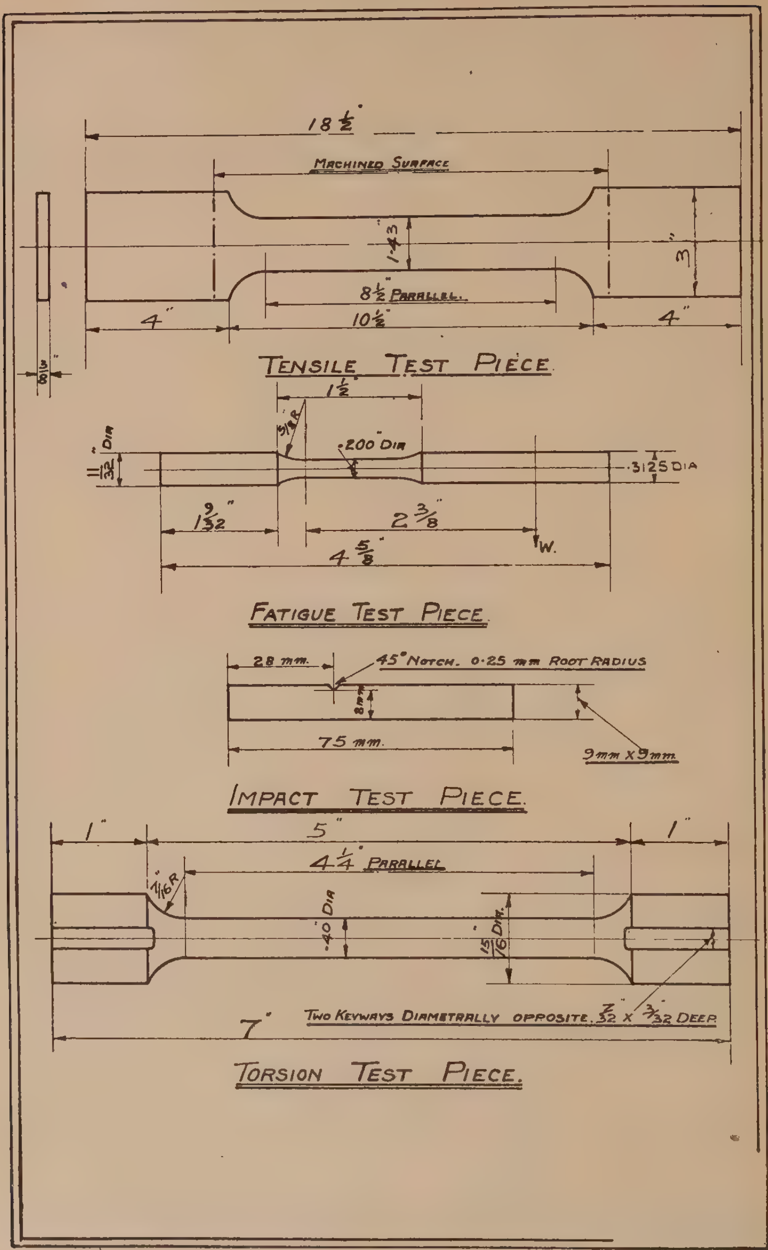

Fig. 1.—Forms of Test-pieces.

6-inch lengths of the plate materials were subjected to the same hardening and tempering operations as the above specimens, and similar-test specimens were then machined from the 6-inch lengths without further heat treatment. Identical procedures were used in making the tests of the two groups of specimens, and the results obtained are summarised in Table VI.

TABLE VI.—*Preliminary Comparative Tests.*

A.—Heat-treated specimens.
B.—Heat-treated specimens, 0·05 inch removed by final grinding.
C.—Specimens cut from heat-treated plates.

Material.	Heat Treatment. (Temperatures in Deg. C.)	Reference.	Fatigue Limit, Tons per Square Inch.	Izod Impact. Ft.-lbs.	Brinell Number.
0·6 per cent. Carbon steel	O.-Q. 950, T. 400	*C*	± 47	...	455
,,	,,	*A*	± 35 (approx.)	...	470
,,	O.-Q. 950, T. 450	*C*	...	11·8	400
,,	,,	*A*	...	11·8	400
,,	O.-Q. 950, T. 500	*C*	± 38	18·0	370
,,	,,	*A*	± 28 (approx.)	15·3	372
,,	,,	*B*	± 37·5	...	370
Silico-manganese steel	O.-Q. 950, T. 500	*C*	± 46	11·7	415
,,	,,	*A*	± 44	18·4	415

O.-Q. = oil-quenched; T. = tempered.

The fatigue limits were obtained by rotating cantilever endurance tests on four to six specimens of each heat treatment, and the impact results were obtained from six specimens of each treatment. It can be seen that although there is little difference in the hardness values, the two methods of test-piece preparation may give differences in fatigue and impact results. In all treatments of both steels it was found that type *C* specimens showed good agreement for individual specimens of the same treatment, and that accurate and reliable results could be obtained. With the exception of the impact tests on the 0·6 per cent. carbon steel, types *A* and *B* specimens did not give good agreement of individual specimens with the same treatment, and the results were not very reliable. It was also found that fatigue test-pieces of this type were liable to warp on quenching, indicating the presence of unknown internal stresses which might influence the final results. Many of the specimens were polished and examined under the

microscope, and some of the A type specimens of 0·6 per cent. carbon steel were found to contain small hardening cracks. These cracks were not visible to the naked eye on a good finished surface, but probably account for the two lowest fatigue results obtained. No evidence of similar cracks was obtained on C type specimens, and, for this material, the separate quenching of the small specimens was obviously undesirable.

As a result of these preliminary tests, it was decided to prepare all fatigue and impact specimens by carrying out the hardening and tempering on 6-inch lengths of plate, and then to machine out the specimens. In adopting this procedure it was also thought that the results would be more representative of the real properties of the material than similar results on small specimens which had been heat-treated after machining.

Tensile Tests.

The dimensions of the tensile test-piece adopted are shown in Fig. 1. Any form of cylindrical test-piece from the $\frac{3}{8}$-inch plate would be very small, and there was little alternative to the use of a flat test-piece and wedge grips. The latter method of gripping is not so satisfactory as a screwed test-piece for accurate work, but the 8-inch test length reduces the defects of the method, and the results obtained in the tests are considered quite satisfactory. The section 1·43 inch $\times$ 0·35 inch on an 8-inch test-length corresponds to the standard form, gauge length $= 11 \cdot 3 \sqrt{}$ (cross-sectional area), and test-pieces in accordance with this form should give directly comparable results for percentage extension. The specimens were cut from the full thickness of the material, heat-treated as shown in Table VII., and then tested for hardness at the enlarged ends. The test length was then ground parallel, so that all surface scale was removed along the test-length. In many cases the uniformity of hardness along the test-length was checked by small ball or diamond indentation tests, and the indentations then removed by additional grinding. A standard 8-inch Ewing extensometer was used for the determinations of the limits of proportionality and moduli of elasticity. The complete results of the tensile tests are given in Table VII. It should be realised

TABLE VII.—*Results of Tensile Tests.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell Number.	Limit of Proportionality. (Tons/In.².)	Yield Stress. (Tons/In.².)	Ultimate Stress. (Tons/In.².)	Extension per Cent. on 8 Inches.	Reduction of Area per Cent.	Modulus of Elasticity. (Lbs./In.².)
0·6% C steel	Normalised, 850	228	32	32·4	55·0	14·9	31	$\times 10^6$ 30·2
,,	O.-Q. 950, T. 400	455	66	93·4	101·8	...	2	29·5
,,	,,	440	67	...	112·0	1·4	3	29·7
,,	,,	455	...	...	110·2	...	...	...
,,	,,	440	...	...	110·5	...	...	...
,,	O.-Q. 950, T. 450	420	60	87·4	91·3	5·5	11	29·8
,,	,,	420	49	79·6	92·5	4·5	10	28·7
,,	O.-Q. 950, T. 500	365	58	73·0	79·0	7·0	18	29·8
,,	,,	365	56	72·1	78·0	7·0	16	30·0
,,	O.-Q. 950, T. 550	335	50	64·8	71·1	6·8	24	30·1
,,	,,	350	53	71·0	77·6	6·4	18	29·7
0·8% C steel	Normalised, 850	255	24	31·8	59·3	11·6	24	$\times 10^6$ 30·0
,,	O.-Q. 900, ...	375	37	62·0	86·1	6·0	8	30·0
,,	,,	360	38	63·5	83·1	8·5	14	30·3
,,	O.-Q. 900, T. 450	363	41	63·6	83·9	7·9	19	30·2
,,	,,	375	41	64·9	84·1	7·0	14	30·3
,,	O.-Q. 900, T. 500	365	42	63·0	81·2	7·9	21	30·2
,,	,,	362	39	68·0	81·9	9·1	17	30·0
,,	O.-Q. 900, T. 550	340	35	57·3	77·4	9·4	26	30·0
,,	,,	336	35	58·8	77·6	9·8	27	30·3
,,	O.-Q. 830, ...	385	32	...	75·5	...	2	...
,,	O.-Q. 830, T. 450	385	32	74·4	85·7	8·2	24	...
,,	O.-Q. 830, T. 500	370	29	57·1	81·3	9·6	27	...
,,	O.-Q. 830, T. 550	350	20	51·5	78·8	10·7	27	...
Silico-manganese steel	Normalised, 950	275	36	47·0	61·2	14·6	35	$\times 10^6$ 30·2
,, ,,	O.-Q. 950, T. 450	452	67	105·5	110·0	5·0	23	30·0
,, ,,	,,	463	66	100·0	106·3	3·4	18	29·8
,, ,,	O.-Q. 950, T. 500	408	63	85·0	92·1	8·4	22	30·0
,, ,,	,,	423	61	81·5	90·5	7·8	21	30·2
,, ,,	O.-Q. 950, T. 550	360	55	72·0	79·6	9·4	25	29·9
,, ,,	,,	360	55	72·0	79·6	10·4	26	30·5
,, ,,	O.-Q. 950, T. 600	340	48	63·0	73·0	12·6	31	30·0
,, ,,	,,	325	...	64·0	72·0	12·5	30	...
,, ,,	W.-Q. 870, T. 450	477	85	102·0	106·7	5·4	28	30·0
,, ,,	,,	520	90	116·0	118·2	2·8	28	29·6
,, ,,	W.-Q. 870, T. 500	402	70	85·0	91·1	7·8	25	29·9
,, ,,	,,	413	70	85·0	91·2	8·0	19	30·3
,, ,,	W.-Q. 870, T. 550	380	60	77·0	84·4	8·8	26	30·4
,, ,,	,,	386	58	...	84·9	8·4	25	30·3
,, ,,	W.-Q. 870, T. 600	355	55	70·0	77·8	10·6	28	30·0
,, ,,	,,	358	54	69·0	77·7	10·4	25	30·0
Chrome-vanadium steel	Normalised, 850	300	46	...	69·6	10·6	47	$\times 10^6$ 30·3
,, ,,	O.-Q. 850, T. 400	500	77	104·5	112·3	...	10	30·6
,, ,,	,,	500	81	107·0	111·0	5·6	14	30·1
,, ,,	O.-Q. 850, T. 475	485	72	103·0	105·2	5·4	25	30·1
,, ,,	,,	485	71	104·0	105·5	4·4	13	30·0
,, ,,	O.-Q. 850, T. 550	415	63	83·0	85·7	7·1	33	30·8
,, ,,	,,	405	63	80·4	83·4	7·4	31	30·3
,, ,,	O.-Q. 850, T. 600	386	55	76·0	79·6	7·4	32	30·6
,, ,,	,,	385	54	75·1	79·4	7·3	30	30·7

O.-Q. = oil-quenched ; W.-Q. = water-quenched ; T. = tempered.

that the order of accuracy of the reduction of area figures is not so high as that normally obtained on cylindrical test-pieces.

Fatigue Tests.

The fatigue tests were made by the endurance method in rotating cantilever machines running at 2200 revolutions per minute. The form of specimen finally adopted is shown in Fig. 1. Pieces of the plate material 6 inches long were heat-treated, tested for hardness, and the specimens then cut out and ground to size. It was proposed to use specimens 0·250 inch in diameter, but it was found that such specimens fractured at the clamping screws in the chuck of the machine, and it was necessary to reduce the effective diameter to 0·200 inch in order to obtain fractures at the point of maximum bending stress. The complete results of the fatigue tests are given in Table VIII.

Table VIII.—*Results of Fatigue Tests.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell No.	Specimen.	Stress. (Tons per Square Inch.)	No. of Reversals of Stress. (Millions.)	Estimated Fatigue Limit. (Tons per Square Inch.)
0·6 % C. steel	O.-Q. 950, T. 400	455	S1H1D	± 48·0	2·39 B	
			S1H1E	± 48·0	2·28 B	
			S1H1F	± 47·1	7·49 B	
			S1H1C	± 46·7	13·52 U	
			S1H1B	± 45·4	0·91 U	
			S1H1A	± 41·3	9·14 U	± 47·0
0·6 % C. steel	O.-Q. 950, T. 450	422	S1H9B	± 44·0	0·24 B	
			S1H9C	± 42·7	0·16 B	
			S1H9D	± 41·8	0·38 B	
			S1H9A	± 40·0	9·85 U	± 41·0
„	„	400	S1H3A	± 45·0	0·15 B	
			S1H3B	± 41·4	0·30 B	
			S1H3F	± 41·4	0·37 B	
			S1H3E	± 40·0	0·32 B	
			S1H3D	± 38·6	17·43 U	± 39·0
0·6 % C. steel	O.-Q. 950, T. 500	370	S1H5B	± 44·0	0·12 B	
			S1H5D	± 41·7	0·16 B	
			S1H5E	± 38·6	7·40 B	
			S1H5F	± 37·2	13·12 U	
			S1H5C	± 36·0	12·98 U	
			S1H5A	± 35·0	5·41 U	± 38·0

O.-Q. = oil-quenched ; T. = tempered ; B. = specimen broken ; U. = specimen unbroken.

TABLE VIII.—*Continued.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell No.	Specimen.	Stress. (Tons per Square Inch.)	No. of Reversals of Stress. (Millions.)	Estimated Fatigue Limit. (Tons per Square Inch.)
0·6 % C. steel	O.-Q. 950, T. 550	353	S1H7E	± 41·3	0·25 B	
			S1H7F	± 38·6	6·68 B	
			S1H8I	± 37·2	9·58 U	
			S1H8G	± 37·2	12·32 U	
			S1H7D	± 34·6	12·48 U	
			S1H7C	± 32·0	15·38 U	± 37·5
0·8 % C. steel	O.-Q. 900, T. 500	377	S2F7B	± 42·6	0·23 B	
			S2F7C	± 41·3	0·38 B	
			S2F7D	± 39·5	10·06 U	
			S2F7A	± 38·6	13·22 U	± 40·0
0·8 % C. steel	O.-Q. 900, T. 550	344	S2F9B	± 40·5	0·22 B	
			S2F9C	± 39·2	0·19 B	
			S2F9D	± 37·8	11·93 U	
			S2F9A	± 36·5	11·79 U	± 38·5
Silico-manganese steel	O.-Q. 950, T. 450	470	S6K25C	± 49·4	0·79 B	
			S6K25A	± 48·9	1·72 B	
			S6K25D	± 48·0	7·94 B	
			S6K25B	± 47·5	25·00 U	± 47·8
Silico-manganese steel	O.-Q. 950, T. 500	415	S6K27F	± 50·0	0·90 B	
			S6K27D	± 47·0	3·48 B	
			S6K27E	± 45·0	19·12 U	
			S6K27B	± 43·5	27·92 U	
			S6K27C	± 43·0	2·78 U	± 46·0
Silico-manganese steel	O.-Q. 950, T. 550	390	S6K29B	± 46·3	0·64 B	
			S6K29D	± 45·4	0·39 B	
			S6K29C	± 45·2	2·03 B	
			S6K29A	± 43·6	14·92 U	± 44·0
Silico-manganese steel	O.-Q. 950, T. 600	337	S6K32A	± 39·6	0·20 B	
			S6K32B	± 38·4	0·40 B	
			S6K32C	± 37·2	6·09 B	
			S6K32D	± 37·2	0·86 B	
			S6K32E	± 35·6	0·75 B	
			S6K32F	± 35·0	12·37 U	± 35·4
Silico-manganese steel	W.-Q. 870, T. 450	470	S6K33B	± 51·0	0·20 B	
			S6K33D	± 50·7	0·82 B	
			S6K33C	± 49·4	14·84 U	
			S6K33A	± 48·0	10·45 U	± 50·0

O.-Q. = oil-quenched ; W.-Q. = water-quenched ; T. = tempered;
B. = specimen broken ; U. = specimen unbroken.

TABLE VIII.—*Continued.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell No.	Specimen.	Stress. (Tons per Square Inch.)	No. of Reversals of Stress. (Millions.)	Estimated Fatigue Limit. (Tons per Square Inch.)
Silico-manganese steel	W.-Q. 870, T. 500	420	S6L5C	± 49·0	0·37 B	
			S6L5E	± 47·6	0·32 B	
			S6L5D	± 47·6	0·41 B	
			S6L5B	± 46·3	11·41 U	
			S6L5A	± 43·6	10·12 U	± 47·0
Silico-manganese steel	W.-Q. 870, T. 550	370	S6L7D	± 43·2	0·35 B	
			S6L7B	± 42·4	1·41 B	
			S6L7A	± 42·1	1·33 B	
			S6L7C	± 40·8	13·21 U	± 41·4
Silico-manganese steel	W.-Q. 870, T. 600	342	S6L9D	± 41·3	3·53 B	
			S6L9B	± 40·8	5·89 B	
			S6L9C	± 39·4	6·48 B	
			S6L9A	± 38·6	10·07 U	± 39·0
Chrome-vanadium steel	O.-Q. 850, T. 400	516	S5G1A	± 54·0	0·05 B	
			S5G1B	± 50·0	0·22 B	
			S5G1D	± 48·6	0·28 B	
			S5G1E	± 47·2	9·39 B	
			S5G1C	± 45·9	11·23 U	± 47·0
Chrome-vanadium steel	O.-Q. 850, T. 475	460	S5G3A	± 50·7	0·12 B	
			S5G3B	± 47·0	0·17 B	
			S5G3D	± 45·4	0·26 B	
			S5G3E	± 44·0	3·29 B	
			S5G3F	± 44·0	0·48 B	
			S5G3C	± 42·7	11·81 U	± 43·5
Chrome-vanadium steel	O.-Q. 850, T. 550	415	S5G5A	± 45·9	0·18 B	
			S5G5D	± 44·5	0·12 B	
			S5G5C	± 43·2	12·52 U	
			S5G5B	± 40·5	10·71 U	± 43·5
Chrome-vanadium steel	O.-Q. 850, T. 600	390	S5G7B	± 43·2	0·24 B	
			S5G7D	± 43·2	0·12 B	
			S5G7C	± 42·0	12·17 U	
			S5G7A	± 40·5	12·22 U	± 42·5

O.-Q. = oil-quenched; W.-Q. = water-quenched; T. = tempered; B. = specimen broken; U. = specimen unbroken.

IMPACT TESTS.

The impact tests were made by the Izod method in a standard 120 ft.-lb. machine. The thickness of the material did not allow the normal 10 × 10 mm. specimen to be used, and a 9 × 9 mm.

TABLE IX.—*Results of Impact Tests.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell Number.	Energy Absorbed. Ft.-Lbs.			Mean Energy Absorbed. Ft.-Lbs.
0·6 % C steel	O.-Q. 950, T. 400	440	3·0 3·8	4·8 4·0	4·0 5·0	4·1
,,	O.-Q. 950, T. 450	410	12·5 12·2	12·0 11·0	11·1 11·9	11·8
,,	O.-Q. 950, T. 500	370	17·0 18·0	17·8 17·8	19·1 18·5	18·0
,,	O.-Q. 950, T. 550	350	18·1 18·0	18·0 19·5	19·0 18·5	18·5
0·8 % C steel	O.-Q. 900, T. 500	376	12·0 15·7	12·5 11·0	12·5 11·3	12·5
,,	O.-Q. 900, T. 550	344	14·0 11·0	13·9 10·5	13·2 12·0	12·4
,,	O.-Q. 830 ...	372	11·4 11·2	11·8 11·3	8·3 15·1	11·5
,,	O.-Q. 830, T. 450	378	11·0 10·0	11·0 7·0	10·5 14·9	10·7
,,	O.-Q. 830, T. 500	380	10·1 11·1	10·0 8·8	11·9 9·9	10·3
,,	O.-Q. 830, T. 550	345	11·0 9·2	15·5 11·5	10·1 12·9	11·7
Silico-manganese steel	O.-Q. 950, T. 450	465	10·2 7·7	8·7 10·0	10·0 8·8	9·2
,,	O.-Q. 950, T. 500	410	10·9 11·5	11·9 12·0	12·0 12·1	11·7
,,	O.-Q. 950, T. 550	389	30·0 15·1	11·5 12·3	18·4 15·1	Mean of five 14·5
,,	O.-Q. 950, T. 600	330	14·8 19·9	16·4 16·5	18·0 17·0	17·1
,,	W.-Q. 870, T. 450	470	9·9 13·0	9·0 8·5	11·0 12·0	10·6
,,	W.-Q. 870, T. 500	420	13·5 14·5	20·0 11·1	11·5 10·3	13·5
,,	W.-Q. 870, T. 550	365	21·8 13·5	15·1 13·0	13·5 34·3	Mean of five 15·4
,,	W.-Q. 870, T. 600	345	16·9 17·0	16·6 20·7	16·8 25·5	18·9
Chrome-vanadium steel	O.-Q. 850, T. 400	518	9·0 9·7	9·0 9·6	7·8 8·7	9·0
,,	O.-Q. 850, T. 475	460	13·2 13·0	13·0 12·4	13·1 13·0	13·0
,,	O.-Q. 850, T. 550	417	21·5 19·0	21·0 19·0	18·3 21·8	20·1
,,	O.-Q. 850, T. 600	390	29·4 30·3	34·5 25·0	29·4 34·5	30·5

O.-Q. = oil-quenched; W.-Q. = water-quenched; T. = tempered.

specimen with a 45° notch, 0·25 mm. root radius, 1 mm. deep was adopted for the tests. The standard notch is 2 mm. deep on a width of 10 mm., so that the specimens used were similar to the standard but had 0·9 of the width. It is to be regretted that it was necessary to depart from the standard 10 × 10 mm. specimen, but the alternative standard 5 × 10 mm. test-piece would have given very low results on some of the harder materials and would have necessitated considerable additional machining. It is considered that the results given by the 9 × 9 mm. specimens can be compared directly with 10 × 10 mm. Izod results by increasing the energy absorbed in the former by $\frac{1}{9}$th. 6-inch lengths of the plate materials were hardened and tempered, tested for hardness, and the specimens then cut out. The specimens were cut out in the direction of the length of the 6-inch plates with the notches parallel to the surface and in the direction of the original 3-inch width. Six specimens were tested for each heat treatment, and the results are given in Table IX. The results of individual tests are given in order to show the uniformity or otherwise of the results obtained for each particular heat treatment.

The form of specimen adopted is shown in Fig. 1.

Torsion Tests.

The dimensions of the torsion test-pieces are shown in Fig. 1, and it was necessary to prepare them from the round bar material. The test-pieces were rough machined, hardened and tempered, and then ground along the test-lengths. The hardness of each specimen was determined by small ball tests on this part, and the indentations removed by a final grinding to the finished diameter. The tests were made in a 3000 lb.-ft. Buckton torsion testing machine, and strains were observed on a 4-inch length by means of a mirror extensometer. The limits of proportionality and moduli of rigidity were obtained from large scale curves of the extensometer readings. No distinct yield-point was observed on any of the specimens. The modulus of rupture was calculated from the usual formula:

$$\text{Torque} = \frac{\pi}{16} f d^3,$$

where f = torsional stress.
d = diameter of test-piece.

The complete results of the torsion tests are given in Table X.

TABLE X.—*Results of Torsion Tests.*

Material.	Heat Treatment. (Temperatures in Deg. C.)	Brinell Numbers.	Limit of Proportionality. (Tons per Square Inch.)	Ultimate Modulus of Rupture. (Tons per Square Inch.)	Modulus of Rigidity. (Lbs. per Square Inch.)	Total Angle of Twist in 4 Inches. (Degrees.)
					$\times 10^6$	
0·6 % C. steel	O.-Q. 950, T. 400	460	39	84·6	11·9	479
		455	46	85·9	11·6	600
,,	O.-Q. 950, T. 450	416	42	73·8	11·8	745
		407	43	73·2	11·7	635
,,	O.-Q. 950, T. 500	365	36	68·1	11·8	1000
		365	38	66·5	11·9	998
,,	O.-Q. 950, T. 550	340	35	61·9	11·8	740
		340	34	59·8	11·8	200
					$\times 10^6$	
0·8 % C. steel	O.-Q. 900, T. 500	368	33	69·3	11·6	615
		368	33	70·3	11·7	944
,,	O.-Q. 900, T. 550	335	31	64·1	11·6	...
		330	31	65·2	11·6	829
					$\times 10^6$	
Silico-manganese steel	O.-Q. 950, T. 450	470	53	86·5	11·6	506
,,	O.-Q. 950, T. 500	412	48	77·2	11·5	906
		412	47	77·8	11·6	785
,,	O.-Q. 950, T. 550	375	43	72·8	11·5	964
		380	43	72·5	11·5	925
,,	O.-Q. 950, T. 600	340	37	65·2	11·6	1098
		330	37	66·4	11·6	1156
,,	W.-Q. 870, T. 450	465	59	89·2	11·5	631
		464	60	88·4	11·5	219
,,	W.-Q. 870, T. 500	424	51	81·3	11·5	1099
		424	51	79·6	11·5	596
,,	W.-Q. 870, T. 550	365	43	69·8	11·6	640
		365	42	68·8	11·5	948
,,	W.-Q. 870, T. 600	343	40	66·8	11·5	724
		345	40	67·0	11·5	789
					$\times 10^6$	
Chrome-vanadium steel	O.-Q. 850, T. 400	515	58	92·4	11·8	125
		515	59	90·5	11·7	120
,,	O.-Q. 850, T. 475	460	51	78·7	11·6	367
		460	51	77·4	11·6	162
,,	O.-Q. 850, T. 550	425	44	69·1	11·6	428
		425	44	67·6	11·7	750
,,	O.-Q. 850, T. 600	400	40	65·0	11·8	440
		400	40	67·3	11·8	567

O.-Q. = oil-quenched ; W.-Q. = water-quenched ; T. = tempered.

Summary of Results.

The mean results of the mechanical tests on each material, excluding torsion, are shown diagrammatically in Figs. 2 to 6. The results of the preliminary hardness tests on 3-inch pieces are shown in Fig. 7. Table XI gives useful ratios between the results of the mechanical tests obtained with each heat treatment.

Table XI.

Material.	Heat Treatment. (Temperatures in Deg. C.)	Mean Brinell Number.	Ratios.		
			Ultimate Tensile Strength to Brinell Number.	Fatigue Limit to Ultimate Tensile Strength.	Fatigue Limit to Brinell Number.
0·6 % C. steel	O.-Q. 950, T. 400	450	0·25	0·42	0·104
,,	O.-Q. 950, T. 450	415	0·22	0·45	0·099
,,	O.-Q. 950, T. 500	370	0·21	0·48	0·103
,,	O.-Q. 950, T. 550	350	0·21	0·50	0·107
0·8 % C. steel	O.-Q. 900,	370	0·23	...	...
,,	O.-Q. 900, T. 450	370	0·23	...	...
,,	O.-Q. 900, T. 500	370	0·22	0·49	0·107
,,	O.-Q. 900, T. 550	340	0·23	0·50	0·113
Silico-manganese steel	O.-Q. 950, T. 450	465	0·23	0·45	0·103
,,	O.-Q. 950, T. 500	415	0·22	0·51	0·111
,,	O.-Q. 950, T. 550	375	0·22	0·55	0·113
,,	O.-Q. 950, T. 600	335	0·22	0·49	0·115
,,	W.-Q. 870, T. 450	475	0·23	0·45	0·105
,,	W.-Q. 870, T. 500	415	0·22	0·52	0·113
,,	W.-Q. 870, T. 550	370	0·22	0·48	0·111
,,	W.-Q. 870, T. 600	350	0·22	0·50	0·111
Chrome-vanadium steel	O.-Q. 850, T. 400	510	0·22	0·42	0·091
,,	O.-Q. 850, T. 475	470	0·22	0·42	0·095
,,	O.-Q. 850, T. 550	415	0·21	0·51	0·105
,,	O.-Q. 850, T. 600	390	0·21	0·54	0·109

O.-Q. = oil-quenched ; W.-Q. = water-quenched ; T. = tempered.

Discussion of Results.

A general comparison of the results of the mechanical tests can be made by comparing Figs. 2 to 6, but a useful comparison

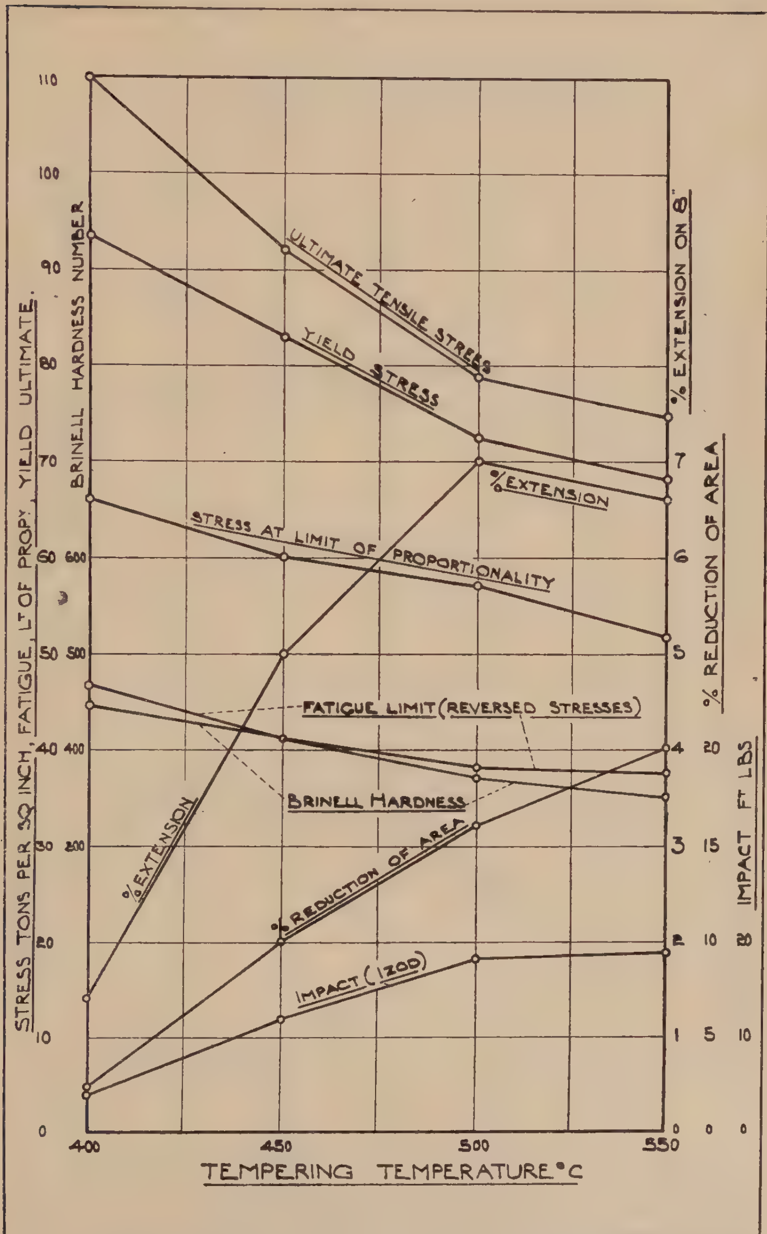

Fig. 2.—Tests on 0·60 per cent. Carbon Steel, Oil-Hardened.

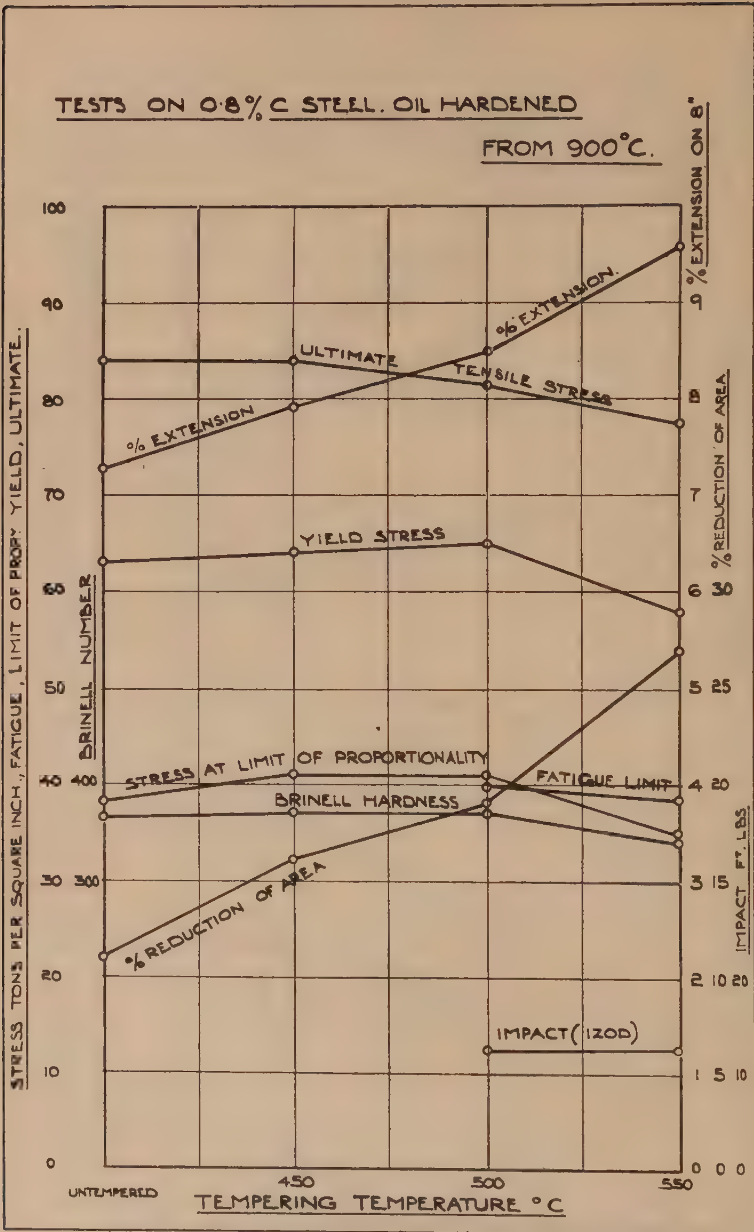

FIG. 3.—Tests on 0·80 per cent. Carbon Steel, Oil-Hardened.

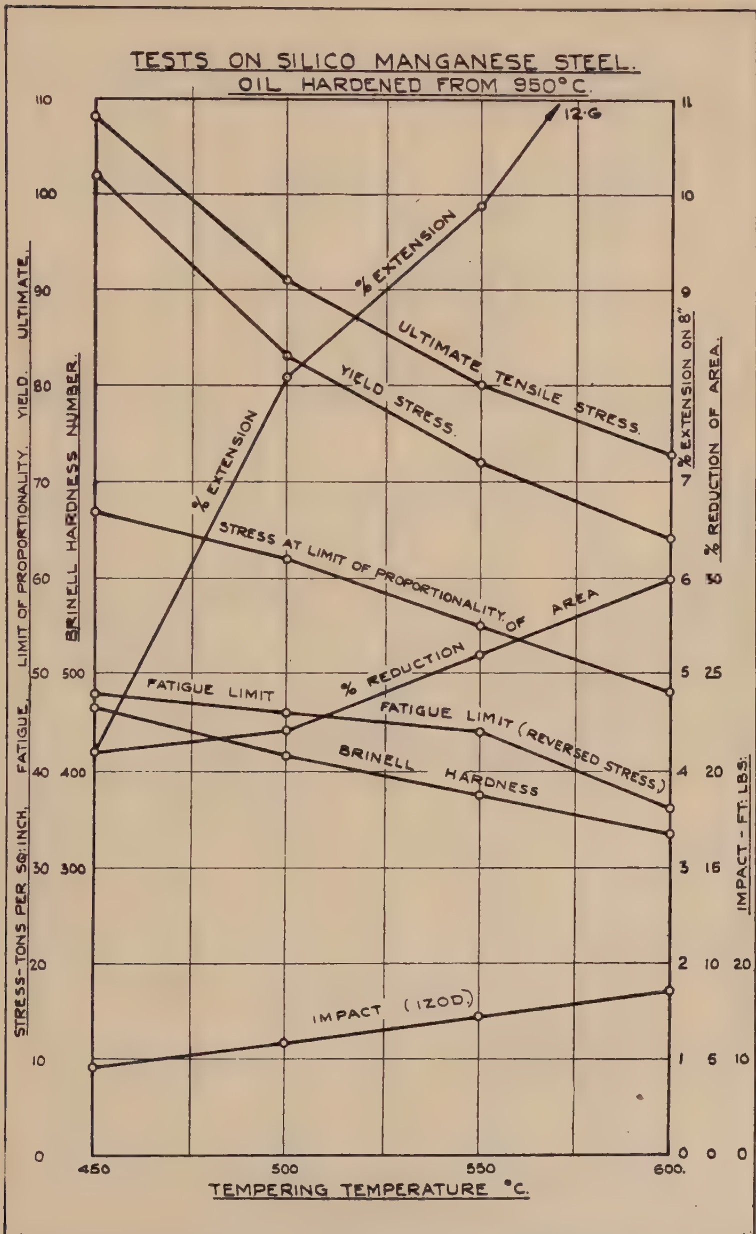

Fig. 4.—Tests on Silico-Manganese Steel, Oil-Hardened from 950° C.

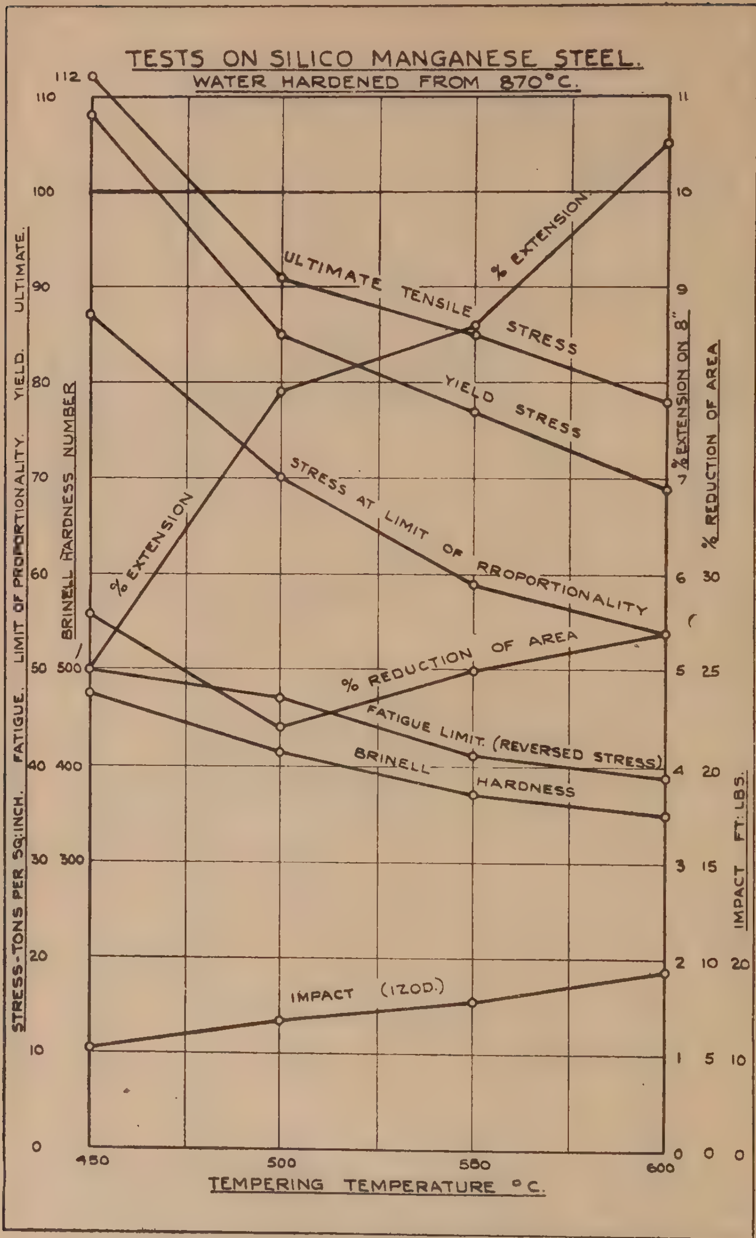

Fig. 5.—Tests on Silico-Manganese Steel, Water-Hardened from 870° C.

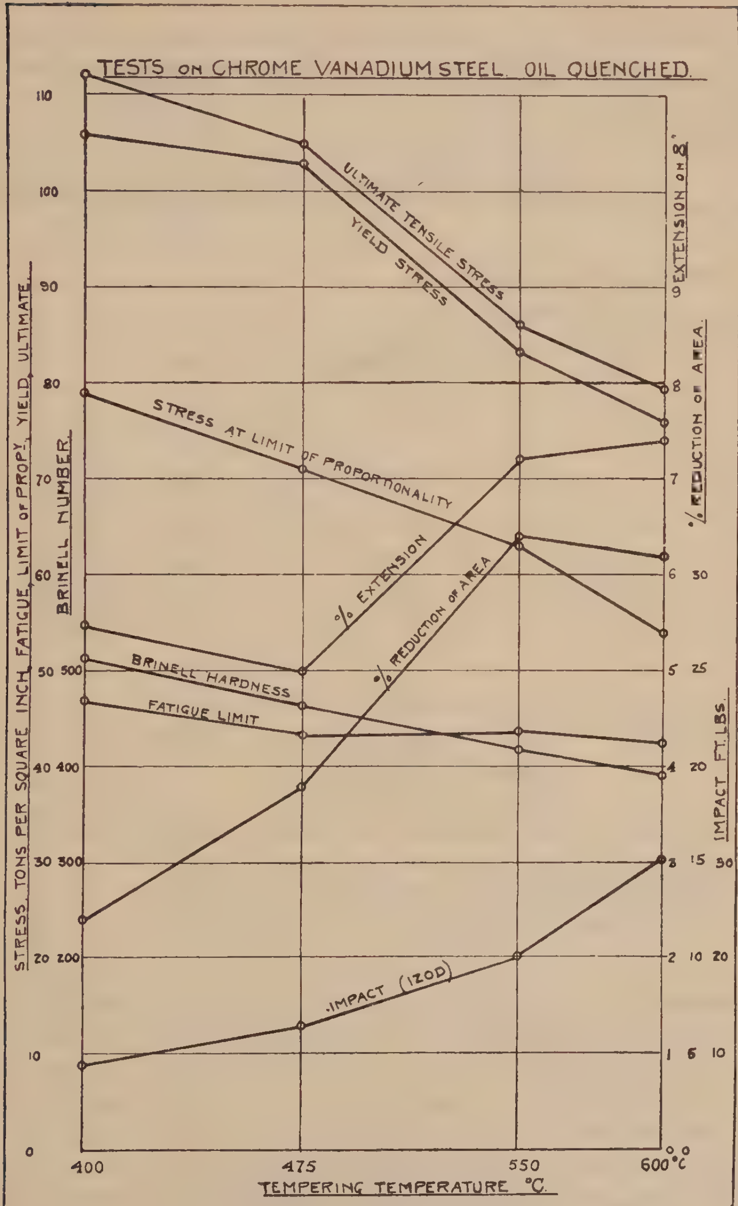

FIG. 6.—Tests on Chrome-Vanadium Steel, Oil-Quenched.

can also be made by plotting the various properties against the Brinell numbers. This has been done in Fig. 8 (Plate XVI.), which presents certain features which are not immediately apparent from Figs. 2 to 6. The main points which the tests appear to have brought out are given below.

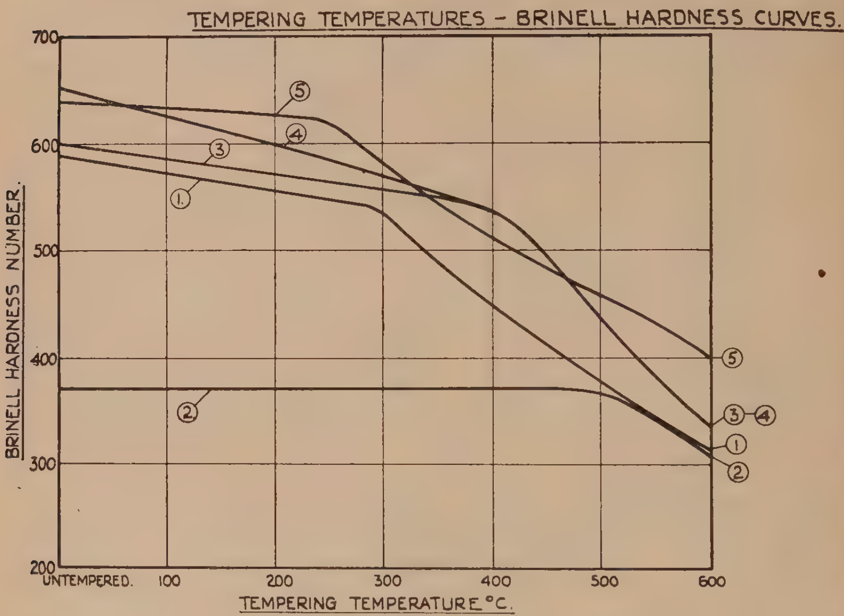

FIG. 7.

1. 0·6 per cent. Carbon Spring Steel. Oil-quenched from 950° C.
2. 0·8 per cent. Carbon Spring Steel. Oil-quenched from 900° C.
3. Silico-Manganese Spring Steel. Oil-quenched from 950° C.
4. Silico-Manganese Spring Steel. Water-quenched from 870° C.
5. Chrome-Vanadium Spring Steel. Oil-quenched from 850° C.

0·6 *per Cent. Carbon Steel.*—It is unusual to adopt oil-quenching on a material of this composition, but probably for this reason the results are of considerable interest. The quenching temperature required for complete hardening is high, but the test results are good for a carbon steel. The elongation and reduction of area are lower than for the other steels of similar hardness and tensile strength, but the fatigue limits, while somewhat lower than the other steels between 350 and 430 Brinell number, are not unduly low. At a Brinell number of 450 the fatigue limit is as

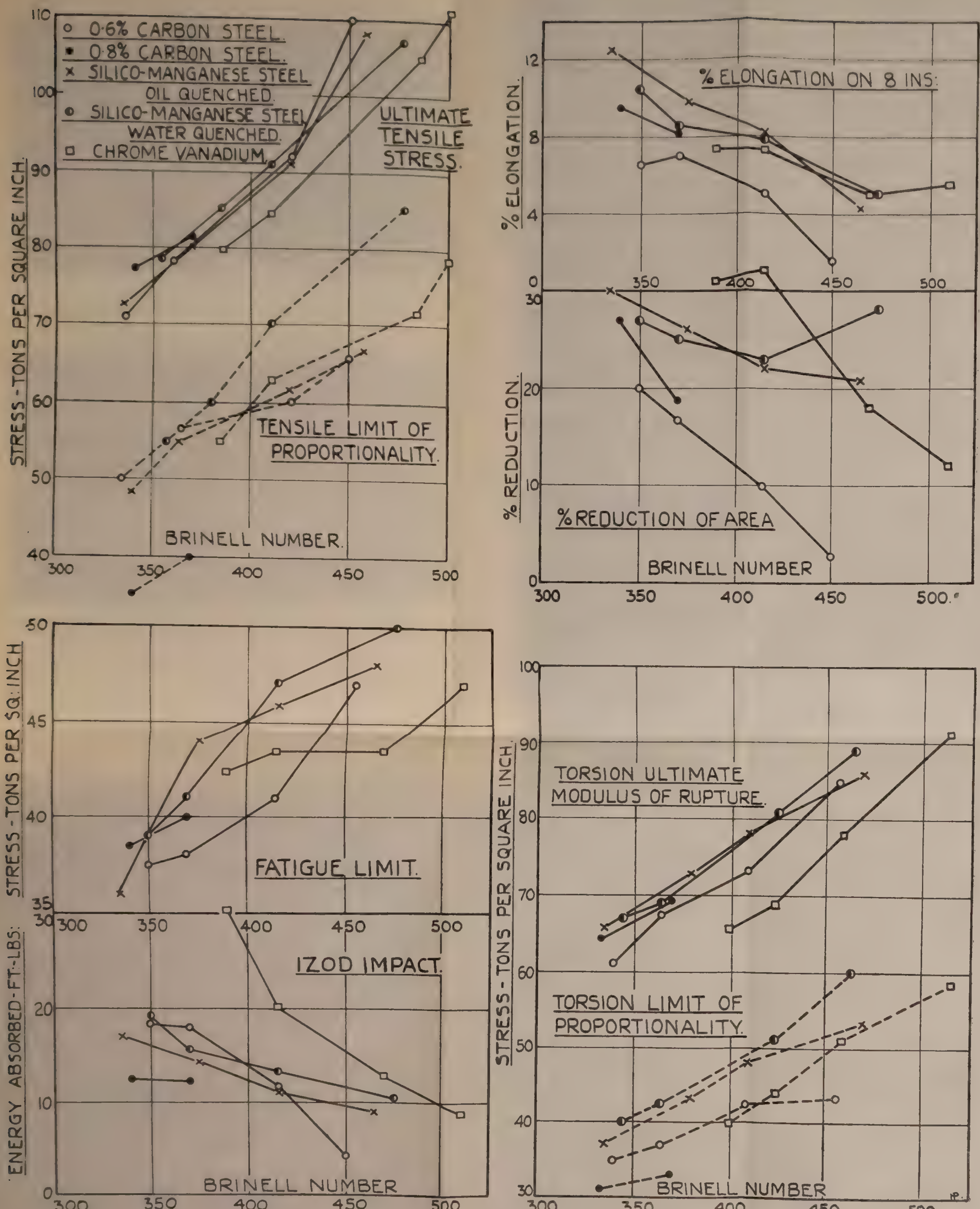

FIG. 8.

[To face p. 288.

FIG. 9.—0·6 per cent. Carbon Steel. Oil-hardened from 950° C. Tempered 550° C. ×300.

FIG. 10.—0·8 per cent. Carbon Steel. Oil-hardened from 900° C. Tempered 550° C. ×300.

FIG. 11.—Silico-Manganese Steel. Oil-hardened from 950° C. Tempered 450° C.

FIG. 12.—Chrome-Vanadium Steel. Oil-hardened from 850° C. Tempered 600° C. ×800.

NOTE.—The above micrographs have been reduced to $\frac{3}{5}$.

high as $\pm$ 47 tons per square inch, against $\pm$ 43·5 for the chrome-vanadium steel and $\pm$ 50 for the water-quenched silico-manganese steel. The corresponding elongation and Izod values are inferior to the alloy steels. The Izod values of the steel at the higher tempering temperatures (and correspondingly lower Brinell numbers) are as good as the values given by the silico-manganese steel.

0·8 *per Cent. Carbon Steel.*—It was pointed out in the remarks on heat treatment that this steel could not be properly hardened in oil even by quenching from 950° C., and hence the effect of tempering, up to 500° C., is very small. Tempering at 550° C. gives a reduction in hardness accompanied by an increase in ductility and a decrease in tensile strength and fatigue limit, but the Izod value is not improved. The limits of proportionality both in tension and torsion are distinctly low, but the fatigue limits are not inferior to the other steels of the same hardness. The results do not show any marked differences in mechanical properties for the two quenching temperatures, but the higher temperature (900° C.) produces more uniform material than the lower temperature (830° C.).

Silico-Manganese Steel.—Consideration of Fig. 7 shows that the distinct change in the slope of the Brinell number tempering temperature curve does not occur until a temperature of 400° C. is reached, compared with 250° C. for the chrome-vanadium steel, and 300° C. for the 0·6 per cent. carbon steel. Above this temperature the rate of decrease of hardness is more rapid for the silico-manganese than for the other steels. Fig. 5 shows that the water-quenched material gives high values for the tensile limit of proportionality at the three higher tempering temperatures, and a similar result is also apparent in the torsion tests. Values of elongation and reduction of area are fairly good in all the tests on both oil- and water-quenched material, while the Izod values are not particularly low. The fatigue limits at the three lower tempering temperatures for either oil- or water-quenched material are superior to the other steels. In general, the water-quenched material appears to be slightly superior to the oil-quenched material.[1]

[1] It should be noted that the fatigue results on individual specimens of the steel, oil-quenched from 950° C. and tempered at 600° C., are somewhat irregular, and it is possible that the value obtained ($\pm$ 36 tons per square inch) is somewhat lower than would be obtained in a repeat test.

Chrome-Vanadium Steel.—It is apparent from the results that the ultimate tensile and torsion strengths are low for this material when compared with corresponding Brinell numbers. Hence if comparisons were made with respect to tensile strength the points for chrome-vanadium steel in Fig. 8 would be moved slightly to the left. It is fairly definite, however, that, with the exception of tempering at 600° C., the chrome-vanadium steel has lower values of fatigue limits than silico-manganese steel of similar tensile strengths or tempered at similar temperatures. The Izod values, however, are distinctly superior to all the other steels. Chrome-vanadium steel, tempered at 600° C. (giving a Brinell number of 400), combines a high Izod value and good reduction of area, with a fatigue limit of $\pm\ 42 \cdot 5$ tons per square inch.

Acknowledgments.

The authors desire to acknowledge the advice and encouragement received from Dr. W. Rosenhain, F.R.S., Chairman, and from the members of Panel No. 1, Springs Research Committee; they are also indebted to Mr. T. E. Rooney, A.I.C., for the chemical analyses, and to Mr. P. L. Thorpe for assistance with the mechanical testing.

DISCUSSION.

Mr. E. H. Saniter (Member of Council) desired to draw attention to Table I. giving the analyses of materials, and to ask the authors how the steels were made; they certainly could not be considered as representative of the steels that were used for spring-making in Great Britain. They were of exceeding purity—in fact, some of them were so pure that he begged leave to doubt the analyses. He had never yet been able to find a British steel which showed less than 0·012 per cent. sulphur, but he noticed that the first of the authors' 0·6 per cent. carbon steels had 0·007 per cent. sulphur, and some of the others were very low, while the statement was made that the chrome-vanadium steel contained only a trace of sulphur—a state of things which he did not think had yet been arrived at even in Sweden. He would, therefore, be very much obliged if the authors would state how the steels were made.

Reference was made at the bottom of p. 267 to an experiment in which, in order to get a 0·6 per cent. carbon steel to harden in oil, it was quenched from 950° C. His first comment in regard to that was that spring-makers would not, as a rule, attempt to quench such a steel in oil, and they would not heat it up to 950° C. to do so. Personally, he considered that that was much too high a temperature.

He would like the authors to state what sort of oil they used for oil-quenching, as, of course, the viscosity of the oil was of enormous importance in regard to the results obtained. In Table VII., results of tensile tests, there was an extraordinary discrepancy between the hardening results obtained on a 0·6 per cent. carbon and a 0·8 per cent. carbon steel. He could not understand why the latter steel would not harden properly, nor why, if the authors discovered that it would not do so, they did not get another steel that would. The 0·6 per cent. carbon steel, stated to have been quenched in oil at 950° C. and tempered at 400° C., gave a tensile stress of 112 tons; that seemed an enormously high figure, which he would never have expected under the circumstances, even when using those temperatures.

Mr. C. E. Stromeyer, O.B.E. (Manchester), said that the experiments carried out by the authors were of great importance, for they confirmed the experience of users of steel springs, that, unless the alternating stresses to which they were subjected were considerably less than their static limits of elasticity, they would have a very short life. He had recalculated the endurance limits from the information contained in the paper, and found that they were considerably below the static limits of elasticity, also mentioned in the paper, and even below the endurance limits as estimated by the authors. It was therefore reasonable to assume that properly determined endurance

limits would be found to be reliable for fixing working stresses, and would probably become standards of comparison. But he (Mr. Stromeyer) thought that full advantage had not been taken of the available means for determining endurance limits as devised by the National Physical Laboratory. It would certainly be interesting to compare the endurance limits found by change of deflection with the above results, and in future trials they should be compared with practical experiences. The method of extrapolating the endurance limits adopted by the authors was a very uncertain one, and he could not understand why, if actual endurance limits had not been obtained, the simple modification of their method, namely, the plotting of the reciprocals of the revolutions, instead of the revolutions themselves, was not resorted to. In some diagrams which he had prepared according to this plan, most of the experiments were found to give straight lines; he had drawn the fatigue line through the uppermost points, on the assumption that small experimental values were due to defects in the test-pieces.

Mr. A. Hultgren (Söderfors, Sweden) thought the results given in the paper, particularly those of the fatigue tests, were most interesting and useful, but that still more interest would be attached to the results of the promised fatigue tests to be made on the steels in the shape of complete springs. He believed that the influence of the surface condition would then manifest itself, perhaps in such a way that conclusions as to the suitability of certain heat treatments for spring steels would be different from those based upon the results of the present paper.

Dr. W. H. Hatfield (Sheffield) said he would make a short reply on behalf of the authors, who would have an opportunity of confirming the statements he made.

Mr. Saniter had raised the question that the steels used in the research were low in sulphur. The authors made the statement that they were high-class steels, provided by a firm of steel-makers. He (Dr. Hatfield) knew they were specially pure steels, made within a specification, and, as Mr. Saniter was aware, electrical steel, for instance, would readily give the values which he had discussed. He anticipated that the authors would have no difficulty in giving an explanation of the 0·8 per cent. carbon steel which did not harden. He thought they would say that, if reference were made to the Table of Analyses, it would be found that the manganese content was 0·3 instead of 0·8 per cent., as in the case of the other spring steels. He was sure the authors would very much appreciate the trouble which Mr. Stromeyer had taken in plotting the values for the fatigue limit; he was very glad that attention had been drawn to that particular aspect of the research, and he considered that the figures given concerning the fatigue range were extremely valuable. He desired to say, from his own point of view, that it was an open question whether the authors should have done so much elaborate mechanical testing on the steels

dealt with in the paper—for instance, the carbon steels. As Mr. Saniter had pointed out, the temperatures were indeed very high for hardening, but he thought the authors were perfectly justified in what they had done. They would say that they were conducting a research, and that they were fully entitled to explore the phenomena of the steels under abnormal conditions, with a view to determining whether the conditions normal to industrial manufacture were the best.

The Authors wrote in reply that they were greatly indebted to Dr. Hatfield for presenting the paper, and for his replies to the discussion.

They thanked Mr. Saniter for his remarks, and while Dr. Hatfield had dealt with most of the points raised by him, they would like to confirm the replies given and to add a little to them. The steels used were all ordered to the B.E.S.A. specification for spring steels, and were supplied to those specifications by leading firms of steel-makers. The materials were undoubtedly very pure, but not purer than could be obtained by the use of electrical processes. For research purposes there was much to be said in favour of using steels of the highest quality, since some, at any rate, of the unknown factors were thereby eliminated. Comparison with less pure materials was relatively easy on the basis of the tests made with the high-grade material.

A quenching temperature of 950° C. was adopted for oil-hardening the 0·6 per cent. carbon steel as a result of a considerable number of preliminary experiments. All the authors' test-pieces were carefully examined for uniformity of hardness, and the procedure finally adopted in the experiments was found to give, on the whole, a better uniformity than quenching at a lower temperature. The results given in the paper showed that that treatment had produced material possessing excellent qualities, and the results were the best possible justification for the adoption of that procedure. The oil used was cotton-seed oil.

The differences between the 0·6 per cent. and 0·8 per cent. carbon steels were probably to be ascribed to the differences in manganese content, as Dr. Hatfield stated. When it was discovered that the 0·8 per cent. carbon steel could not be satisfactorily hardened, further work on that material was suspended while the other steels under investigation were examined.

Since the tests described in the paper were made, fatigue tests had been carried out on complete springs made up from the 0·6 per cent. carbon steel, oil-quenched from 950° C. and tempered, and it was anticipated that the results would be published shortly.

Observations from Mr. Stromeyer on the subject of fatigue were always of interest, but the authors could not agree with him that as a general rule fatigue limit values bore any definite relationship to the static elastic or proportional limits. Indeed, two of the authors had been directly concerned in independent investigations on ductile materials, in which it was shown that fatigue limit values could be definitely greater than either the proportional limits or even the

original static yield stresses of the materials.[1] For spring steels, high proportional limits were advantageous, but did not necessarily indicate high fatigue limits; the ultimate strength appeared to be a much better index of the fatigue limit than the proportional limit. In the present tests results were given for the two carbon steels tempered at 500° C.; the ultimate stresses and fatigue limits were about the same in both cases, but the proportional limits differed considerably. For the 0·8 per cent carbon steel tempered at 500° C., the fatigue limit was greater than the static proportional limit.

Mr. Stromeyer appeared to have some doubt as to the accuracy of the fatigue limit determinations. The authors desired to say that considerable care had been exercised in making those determinations, and that they were confident that the values given were accurate, and representative of the materials concerned. In making fatigue tests on hardened and tempered materials a high standard of workmanship was required in machining the test specimens, and it was also essential that the specimens should be uniform. Attention had been given to both those points in making the tests, and the authors thought that the agreement obtained between different specimens with the same treatment was quite satisfactory, when the nature of the materials was considered. The method of estimating the fatigue limit from endurance tests on four to six specimens was the one in normal use at the National Physical Laboratory, and was generally known as the "bracketing" method. Experience of fatigue testing, both in England and in America, in which tests had been made for several hundreds of millions of reversals, had shown that a well-defined "knee" was obtained in the log $S - \log N$ curves for steel (S = stress, N = number of reversals at failure) when the value of N was between 2 millions and 10 millions, and that any downward slope of the curve with increasing reversals beyond the "knee" was negligible. In view of that, it was evident that for normal practical purposes there was no need to pursue an endurance test beyond about 10^7 reversals, and that values obtained by extrapolating reciprocals of N might lead to erroneous results.

In regard to the change of deflection method mentioned by Mr. Stromeyer, it had been found by experience that the method was not reliable for high tensile materials such as those under investigation, and that the "bracketing" method of endurance test on a 10^7 reversal basis was much more accurate.

In reply to Mr. Hultgren, the authors understood that a report on fatigue tests of complete springs would be issued shortly by the Springs Research Committee. The complete spring tests appeared to show that the surface conditions had an appreciable effect on the results obtained, and the matter was now being investigated.

[1] Hankins, *Reports and Memoirs of the Aeronautical Research Committee*, 1921, No. 789; Gough and Hanson, *Proceedings of the Royal Society*, 1923, (A), vol. civ. p. 538.

THE CARBURISATION AND DECARBURISATION OF IRON AND SOME INVESTIGATIONS ON THE SURFACE DECARBURISATION OF STEEL.*

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The surface decarburisation of steel is a cause of much trouble both to the manufacturer and to the consumer. The steel is especially exposed to this reduction of its carbon content when heated for rolling or forging, and also during its heat treatment as for annealing and hardening. In cases of tensile deformation the tension as well as formation of oxide scale may certainly often reduce the decarburisation of a surface section to a harmless minimum, and decarburisation caused by annealing may, under favourable circumstances, be removed by mechanical working with cutting tools, or by grinding the cold steel. Very often, however, the working is not, or cannot be made, sufficiently extensive for this purpose, and it is therefore desirable that the surface decarburisation should be prevented.

For the purpose of making investigations regarding the problem of surface decarburisation, Jernkontoret two years ago granted a subvention to the authors. During the extensive studies of literature which preceded the planning of the work, the previous investigations regarding the influence of different gases on steels were found to be very uncertain and partly contradictory as to their results. It was therefore necessary to subject this question to repeated analyses. These investigations are presented in the following, as well as an account of some direct researches concerning surface decarburisation. In this latter respect the work is as yet not concluded.

* Received June 28, 1926.

I. THE EQUILIBRIA OF THE CARBURISATION AND DECARBURISATION OF IRON.

1. THE CARBURISATION AND DECARBURISATION OF IRON IN AN ATMOSPHERE OF CO_2–CO.

Theory.—The main course of the reaction in the carburisation and decarburisation of iron in an atmosphere of carbon dioxide and carbon monoxide is:

$$3Fe + 2CO \rightleftarrows Fe_3C + CO_2 \quad . \quad . \quad . \quad . \quad (1)$$

The purport of this chemical reaction as well as its dependence on different factors is made clear by comparing the reaction with the course of the oxidation of metals as well as the reduction of their oxides.

As an example may be quoted the reaction $FeO + CO \rightleftarrows Fe + CO_2$, which is presumed to consist of a double dissociation process, namely, the dissociation of the iron oxide into iron and oxygen, and the dissociation of carbon dioxide into carbon monoxide and oxygen:

$$2FeO \rightleftarrows 2Fe + O_2,$$
$$2CO_2 \rightleftarrows 2CO + O_2.$$

Consequently it may be presumed that the gaseous phase of the system, besides carbon dioxide and carbon monoxide, also holds a certain quantity of oxygen. The partial pressure of this, although too small to be ascertained by direct measurement, is nevertheless capable of estimation according to thermo-dynamic formulæ.

At each temperature the oxide has a certain constant oxygen pressure; likewise, each composition of carbon monoxide and carbon dioxide at each temperature shows a definite oxygen pressure. According to the law of mass action the oxygen pressure of the gaseous phase at a certain temperature is dependent on the relation between the concentration of the carbon dioxide and the carbon monoxide, inasmuch as it rises with increasing content of carbon dioxide. If the oxygen pressure of the gaseous phase is lower than that of the oxide, the latter will be reduced; if it be higher, the metal present becomes oxidised. These conditions are, however, strictly valid only on the assumption that

the oxide is insoluble in the metal. If, on the other hand, the oxygen can form solid solutions with the metal, which is probably the case with iron oxide and iron, the equilibrium conditions are rendered more complicated by the fact that the oxygen pressure of the solid solution varies with the concentration of the oxide. A more pronounced equilibrium is obtained in the reaction in question, where the stable solid phases, instead of FeO and Fe, consist of FeO, and Fe saturated with FeO. An infinite number of equilibria are further to be found in lower oxide concentrations.

A similar view applies as to the course of the reaction which takes place during the carburisation and decarburisation of iron. The reaction (1) above referred to may be supposed to consist of the two dissociations :

$$Fe_3C \rightleftarrows 3Fe + C \quad . \quad . \quad . \quad . \quad (2)$$

and

$$2CO \rightleftarrows C + CO_2 \quad . \quad . \quad . \quad . \quad (3)$$

presuming that the gaseous phase contains a small—though not measurable—amount of carbon vapour, *i.e.* that the carbon has a certain osmotic pressure or carbon pressure. This carbon pressure is constant for the elementary carbon at a given temperature, but is variable for different carbon modifications. The carbon pressure of the gas, on the other hand, according to the law of mass action, is dependent not only on the temperature but also on the relation between the concentration of the carbon dioxide and the carbon monoxide, as well as on the total pressure of the gases. A higher content of carbon monoxide and a higher pressure brings about a higher carbon pressure. If the concentration of the carbon monoxide, the carbon dioxide, and the carbon vapour be designated as [CO], [CO_2], and [C_3] respectively, according to the law of mass action, the following equation will be valid for the dissociation of the carbon monoxide (3) :

$$[CO]^2 = k_3 . [C_3] . [CO_2] \quad . \quad . \quad . \quad . \quad (3\text{A})$$

where k_3 is the dissociation constant of the carbon monoxide. When the gaseous phase is in equilibrium with the carbon, the concentration of the carbon vapour is constant (= the carbon pressure of the carbon). Accordingly, equation (3A) may be written

$$\frac{[CO]^2}{[CO_2]} = K_3 \quad . \quad . \quad . \quad . \quad . \quad (3\text{B})$$

where $K_3 = k_3 . [C_3]$ = the equilibrium constant for reaction (3). In this case k_3 and $[C_3]$, and consequently also K_3, are only functions of the temperature.

With analogous notations, the following equation may hold good for reaction (1):

$$[CO]^2 = k_1 . [C_1] . [CO_2] \quad . \quad . \quad . \quad . \quad (1\text{A})$$

where $k_1 = k_3$ = the dissociation constant of the carbon monoxide. $[C_1]$ is the carbon pressure of the iron carbide, and thus $= [C_2]$ according to equation (2), and equation (1A) may be given as:

$$\frac{[CO]^2}{[CO_2]} = K_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (1\text{B})$$

where $K_1 = k_1 . [C_1] = k_3 . [C_2]$.

Consequently we find that—

$$\frac{K_1}{K_3} = \frac{k_3 . [C_2]}{k_3 . [C_3]} = \frac{[C_2]}{[C_3]} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

i.e. the equilibrium constants of reactions (1) and (3) stand in the same relation to each other as the carbon pressures of the iron carbide and the elementary carbon respectively.

On account of the fact that carbon is able to form solid solutions with iron, $[C_2]$, unlike $[C_3]$, is however not only a function of the temperature, but is also dependent on the carbon concentration of these solid solutions. Evidence of conditions is afforded by Fig. 1.

Fig. 1*a* shows part of the iron-carbon diagram. Below Ac1 (at about 720° C.) two solid phases appear, namely ferrite and cementite. Above that point the system consists either of one or of two solid phases. Between the points A' and A (0 to 0·35 per cent. carbon) the system, at a temperature of, say, 800° C., contains ferrite and austenite; between A and B (0·35 to 1·05 per cent. carbon) austenite only; while between points B and B' it contains austenite and cementite. The variation in carbon content of the austenite within these ranges is indicated by Fig. 1*b*. The carbon content of the austenite is constant below the point A, corresponding to a percentage of about 0·35; the quantities of ferrite and austenite respectively of course vary according to the total carbon content of the alloy, but at all events the austenite cannot hold less than 0·35 per cent. carbon. Between points A and B, where the alloy consists only of austenite, the carbon content of the latter is the same as that of the former. At B

and above that point the austenite is saturated with carbon, its composition consequently being constant. A higher percentage of carbon in the alloy only alters the amount of cementite and saturated austenite respectively.

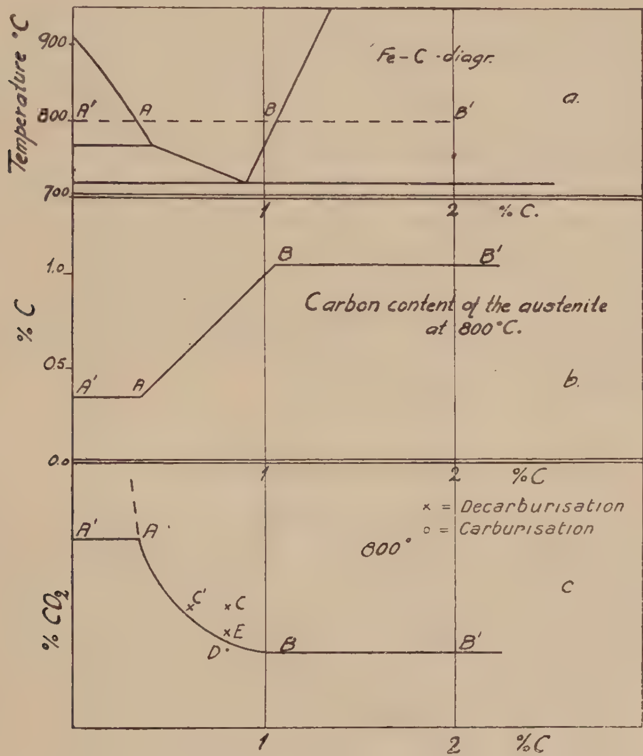

FIG. 1.

If reaction (1) be regarded from the point of view of the Gibbs' phase rule, it is found that the system is bivariant in presence of two solid phases, and trivariant in presence of one solid phase (between points *A* and *B*), the additional variable in the latter case being the carbon percentage or the carbon pressure of the austenite. Consequently the CO_2 content of the stable gas ought to vary according to the carbon content of the alloy in the manner shown in Fig. 1*c* (a higher CO_2 content implies a lower carbon pressure). Along *A'A* an equilibrium is established between the gas and ferrite and austenite of the lowest concentration; the

same will be seen from A to B, between the gas and austenite, the percentage of carbon of which rises. Likewise an equilibrium prevails along BB' between the gas and cementite and saturated austenite.

If it were possible that austenite, at 800° C., could have a lower carbon content than 0·35 per cent., then the curve AB would continue to rise, along the dashed line, asymptotically approaching the ordinate axis. This not being the case, it will be intersected by the line $A'A$ at the point A, which gives the carbon content of the alloy, whose A3 is situated at 800° C.

It is far more difficult to indicate the intersection point B of the curve AB and the line BB'. Certain arguments based on the theory of the phase rule, and which, in order to avoid repetition, will be dealt with later in the discussion of the results obtained, seem, however, to indicate that there is no real intersection point; instead, the line BB' emanates from the point B, as a tangent to the curve AB.

Plan of the Investigation.

The earlier experimental investigations on the reaction $3Fe + 2CO \rightleftharpoons Fe_3C + CO_2$, which will be referred to later, having been both incomplete and contradictory, it was deemed necessary to try to re-determine the equilibria of the reaction. Determinations of this kind have generally been performed in such a way that in a closed vessel a reaction was brought about between a certain amount of finely divided iron or iron oxide and carbon dioxide or carbon monoxide at a certain temperature, the progress of the reaction being followed by observing the changes within the gas as well as those in the solid phase. The results obtained in this way are often very difficult to interpret; besides, they are often misleading on account of the influence of the speed of the reaction. Further, this method of studying the carbide formation in iron is very complicated, and may even be rendered impossible by the process of oxidation which sets in at the same time as the formation of carbides. These difficulties are perhaps best of all evidenced by a paper, just published by Schenck [(1)] as the result of about twenty years' work on this subject.

In order to avoid the difficulties mentioned above, a totally

different method of procedure was adopted, viz. of following analytically the variations in carbon content of the solid phase during its heating in a current of carbon dioxide and carbon monoxide of constant composition; in this way the stable state of reaction (1) was approached from both sides. As the oxidation reactions might exert too great an influence, thus leading to faulty results, it was not deemed advisable to use a primary material consisting of finely divided iron for the purpose of obtaining a greater reaction speed. Instead, thin, milled cuttings of pure carbon steels, with varying carbon contents and low percentages of manganese and silicon, principally consisting of Swedish acid Bessemer steel, were used for these investigations.

The position of such an "isotherm," as is shown graphically in Fig. 1*c*, may be ascertained by heating a steel with 0·80 per cent. carbon for a certain number of hours in a gas mixture, the CO_2 content of which is indicated by the point C. It then appears that the sample has become decarburised to C'. The CO_2 content of the gas mixture is lowered to point E and a fresh sample of the same steel is heated; this also shows decarburisation, though less. The CO_2 content is then still lowered, to point D, and it appears that this sample is slightly carburised. Consequently the equilibrium curve is situated between the points E and D. Accordingly, by determining a sufficient number of samples, the entire curve can be plotted, so as to give the dividing line between those samples which have been carburised and those that have shown decarburisation.

The total partial pressure of the carbon monoxide and carbon dioxide has been kept at 0·4 atmosphere during all the investigations by giving the gas mixture the composition of 60 per cent. nitrogen and 40 per cent. carbon monoxide plus carbon dioxide. The latter step was taken mainly in order to lessen the risks of precipitation of carbon. As will be seen later, a lower pressure also lessens the risk of formation of oxide in the iron.

Experimental Arrangement and the Working of the Determinations.

The experimental arrangement is shown diagrammatically in Fig. 2. The required gas mixture, consisting of nitrogen, carbon monoxide, and carbon dioxide, was mixed in the lower

bottle (1) which communicated with the upper pressure vessel (2) by means of a syphon. Each bottle held about 40 litres. Later, with the view of saving time, another equally large gasometer-system was introduced, which enabled a gas mixture to be prepared while the other system provided gas for the experimental furnace. As the gas mixtures tended to dissolve partially in the liquid used to maintain the pressure in bottle (1), the surface of the liquid (10 per cent. salt solution) was covered with paraffin oil to a depth of 10 millimetres. This appeared to answer fairly well, inasmuch as the variations in the composition of the gas ceased to exert any influence on the progress of each experiment. During the experiment, however, some gas was drawn off at intervals, and analysed, in order to maintain a constant control of its carbon dioxide content.

The nitrogen gas, which originally contained 3 to 4 per cent. of oxygen, was supplied from a cylinder. It was first passed through two wash-bottles containing sulphuric acid (18), and then through a furnace (19) filled with fine copper wire gauze, heated to about 800° C. The nitrogen was thus purified from oxygen, and then passed direct to the gasometer.

The carbon dioxide was also supplied from a cylinder, being led through a wash-bottle containing sulphuric acid (20), and then direct to the gasometer.

The carbon monoxide was generated by concentrated sulphuric acid and formic acid at about 140° C. in the flask (21) which, by means of a special arrangement, could both be drained of the spent liquid and refilled with sulphuric acid without allowing any entry of air. The formic acid was expelled from the bottle (22) by admitting carbon dioxide under pressure, in order to overcome the counter-pressure in the flask. The carbon monoxide formed was practically pure, according to analysis, and was passed through a wash-bottle containing sulphuric acid (23) into the gasometer.

On the way to the experimental furnace the prepared gas mixture was allowed to pass through a drying apparatus containing sulphuric acid (3) and a U-tube containing calcium chloride and phosphorus pentoxide (4) and was then led over a glowing copper gauze in the furnace (5) in order to enable any oxygen, still present in the gas, to combine with the carbon monoxide and form carbon dioxide. Finally, the gas was further

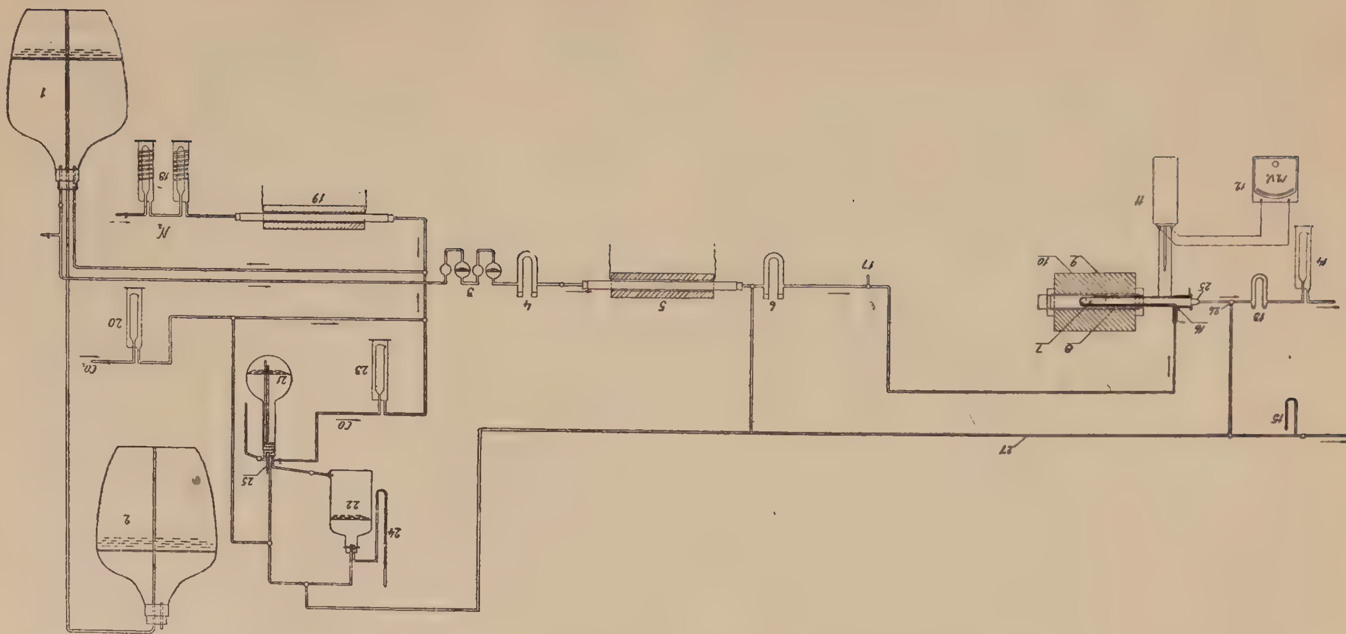

FIG. 2.

dried in the U-tube (6) by means of phosphorus pentoxide, and it was then considered to be ready for admission into the experimental furnace. Gas for testing was withdrawn through the three-way cock (17).

The experimental furnace consisted of a tube of fused silica (8) closed at one end, with a length of 360 millimetres and internal diameter 26 millimetres. The gas was admitted at one end of this tube, by means of a special supply tube. After the introduction of the specimen a glass stopper (25), provided with a plane ground flange, was fastened by means of some easily fused sealing-wax (Chatterton Compound, Qual. 1) to the open end of the tube, which also had a plâne ground flange. A flexible water-cooled lead pipe (16) was twisted around the front part of the tube in order to afford the proper cooling. The gas was allowed to escape from the furnace by the three-way cock (26), then through the U-tube (13) filled with phosphorus pentoxide and the sealing vessel (14), containing sulphuric acid, and finally out into the open air. By means of the three-way cock (26) the furnace could be placed in connection with the vacuum tube (27) which was attached to a mercury vapour pump.

The heating was effected by means of a platinum-wound furnace of the Heraeus type (9) which could be pushed backwards and forwards, so as to permit of quickly heating and cooling the specimen. The advantage of this was that no disturbing reactions had time to take place during the heating and cooling of the specimen.

The temperature was measured by means of a platinum-platinum-rhodium thermocouple placed outside the silica tube, with the hot junction just in the centre below the specimen. The free ends were kept at a constant temperature in a thermos flask (11). An investigation of the temperature-distribution in the furnace at 800° C. showed the temperature at the ends of the specimen to be 10° below that at its centre. Therefore, during the trials at this temperature, the furnace was adjusted for 805° C., the temperature of the specimen consequently varying between 795° and 805° C.

The preparation of the different steel specimens was performed with the utmost care on a slow-running milling machine, so as to avoid the possibility of the cuttings becoming oxidised.

About 3 grammes of cuttings were weighed for each trial and placed in a magnesia boat (7) 50 millimetres long, 10 to 12 millimetres wide, and 6 millimetres high. As the silica content of the magnesia boat amounted only to about 0·5 per cent., all disturbing reactions between the specimen and the boat can be considered as excluded.

The trials were carried out in the following manner. After carefully weighing the magnesia boat alone and then together with the specimen, it was placed in the silica tube, which was then closed by means of the glass stopper, as indicated above. The tube was evacuated to a pressure of less than 1 millimetre mercury gauge, the cock (17) meanwhile being closed. Its tightness was then tested during a couple of minutes, after which it was filled with gas. After having been evacuated and refilled three times, the tube was considered to be perfectly free from air and moisture. Some gas was drawn off through the cock (17) and analysed, whereupon the furnace, somewhat overheated, was pushed over the tube, and the sample attained the desired temperature in ten to fifteen minutes.

The gas current was switched on at once with a velocity of 1 to 3 litres per hour. An accelerated speed was used in cases where a precipitation of carbon was expected. The temperature of the furnace was always regulated by hand, since preliminary trials in the use of automatic regulation of the temperature proved unsuccessful. The temperature variation was very slight, at the utmost 2° to 3°. At the end of the experiment the furnace was quickly pushed backwards, so that the specimen was cooled below red heat in a few minutes. When it was perfectly cold, the glass stopper was removed from the tube; the boat was taken out and weighed together with the specimen as well as separately after having been freed by means of a brush from any small steel cuttings which might have adhered. It was thus possible to calculate the changes of weight of the specimen; no real accuracy, however, was attained, on account of the possibility of small cuttings remaining in the boat, and also of the boat getting damaged during the cleaning out.

Two analyses of carbon of each specimen of the treated cuttings were made by combustion in oxygen and a subsequent weighing of the carbon dioxide formed. In certain cases where

there was a very slight change in the carbon content of the specimen, carbon analyses were simultaneously made on the primary material also. The accuracy of the carbon analyses proved very satisfactory; the results of duplicate analyses never varied by more than 0·01 per cent.

Complete isotherms were determined at 1100°, 1000°, 900°, 800°, 750°, and 710° C., as well as the equilibrium ferrite-austenite at 850° C. The results are recorded in Tables II. to VIII., and are shown graphically in Fig. 3. The index numbers of the steels used and their analyses are to be found in Table I.

TABLE I.—*Analyses of Steels.*

No.	Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.	Chromium.	Nickel.	Tungsten.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	0·69	0·18	0·04	n.d.	0·007	...	...	...
2	0·71	0·40	0·11	0·029	0·017	...	...	...
3	0·72	0·24	0·05	n.d.	0·008	...	...	...
5	0·78	0·27	0·06	,,	0·010	...	...	...
6	0·82	0·24	0·05	,,	0·009	...	...	...
7	0·85	0·23	0·05	,,	0·010	...	...	...
8	0·90	0·23	0·04	,,	0·009	...	...	...
14	1·02	0·27	0·05	,,	0·006	...	...	...
15	1·01	0·18	0·04	,,	0·007	...	...	...
16	1·01	0·21	0·05	,,	0·008	...	...	...
17	1·10	0·43	0·13	0·030	0·017	...	...	...
18	1·13	0·41	0·22	0·033	0·021	...	...	...
19	0·19	0·23	0·04	0·031	0·008	...	...	...
20	0·44	0·25	0·06	0·028	0·007	...	...	...
21	0·55	0·25	0·06	0·031	0·005	...	...	...
22	1·21	0·18	0·04	0·027	0·006	...	...	...
23	1·58	0·49	0·23	0·020	0·006	...	...	...
24	0·08	0·30	0·01	n.d.	n.d.	...	...	...
25	0·02	trace	0·05	0·005	0·005	...	...	...
26	0·42	,,	0·06	0·007	0·005	...	...	...
28	1·08	,,	0·08	0·005	0·010	...	...	...
29	2·32	,,	0·10	n.d.	n.d.	...	...	...
30	0·39	0·61	1·75	0·021	0·018	...	...	...
31	1·03	0·41	0·32	0·019	0·013	1·61	...	...
32	0·56	2·02	0·26	0·022	0·017	...	...	...
33	0·83	n.d.	n.d.	n.d.	n.d.	...	about 2·0	...
34	0·63	,,	,,	,,	,,	...	...	about 2·0
36	1·43	0·50	0·29	0·021	0·011	0·85	2·18	...
37	0·03	n.d.	n.d.	n.d.	n.d.	about 1·5	...	...
38	1·06	0·31	0·20	0·024	0·016	1·29	...	...
39	0·42	n.d.	n.d	n.d.	n.d.	about 14·0	...	...

n.d. = not determined.

TABLE II.—1100° *C.*

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
23	0·4	1·58	1·50	− 0·08	+ 0·02	2·5
2	0·5	0·71	0·62	− 0·09	0	3·0
19	0·85	0·19	0·15	− 0·04	0	2·5
19	1·0–1·1	0·19	0·17	− 0·02	0	3·0
20	1·0–1·1	0·44	0·18	− 0·26	− 0·24	3·0
25	2·4	0·02	0·06	+ 0·04	+ 0·10	2·5
19	2·4	0·19	0·07	− 0·12	− 0·03	3·0
25	3·7	0·02	0·04	+ 0·02	+ 0·07	2·5
25	8·0	0·02	0·02	0	+ 0·09	2·5

TABLE III.—1000° *C.*

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
20	0·4	0·44	0·62	+ 0·18	+ 0·17	2·5
23	0·4	1·58	1·57	− 0·01	+ 0·09	3·5
21	0·8	0·55	0·41	− 0·14	− 0·10	3·0
19	1·0–1·1	0·19	0·26	+ 0·07	+ 0·09	3·0
20	1·0–1·1	0·44	0·33	− 0·11	− 0·10	3·0
25	2·6	0·02	0·10	+ 0·08	+ 0·09	3·0
19	2·6	0·19	0·12	− 0·07	− 0·02	3·0
19	3·4	0·19	0·09	− 0·10	− 0·03	4·0
25	8·0	0·02	0·03	+ 0·01	+ 0·05	2·5

TABLE IV.—900° *C.*

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
23	0·55	1·58	1·64	+ 0·06	+ 0·16	3
21	0·6	0·55	0·65	+ 0·10	+ 0·12	4
6	0·65	0·82	0·84	+ 0·02	+ 0·02	4
23	0·75	1·58	1·43	− 0·15	− 0·05	4
16	1·0	1·01	0·91	− 0·10	− 0·09	4
6	1·0–1·1	0·82	0·71	− 0·11	− 0·11	4
20	2·3	0·44	0·35	− 0·09	− 0·10	4
19	2·3	0·19	0·31	+ 0·12	+ 0·14	4
20	3·1	0·44	0·24	− 0·20	− 0·20	4
19	3·1	0·19	0·21	+ 0·02	+ 0·03	4
19	4·0	0·19	0·18	− 0·01	+ 0·02	4
25	7·6	0·02	0·06	+ 0·04	+ 0·07	6
25	9·8	0·02	0·04	+ 0·02	− 0·23	4
25	11·0	0·02	0·02	0	− 0·10	3

Table V.—850° *C.*

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
24	5·4	0·07	0·14	+ 0·07	− 0·11 (?)	4
24	5·9	0·07	0·12	+ 0·05	+ 0·03	4
24	6·1	0·07	0·07	0	− 0·02	4
24	6·3	0·07	0·05	− 0·02	− 0·08	4

Table VI.—800° *C.*

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
14	0·4	1·02	1·12	+ 0·10	+ 0·09	4
23	2·3	1·58	1·61	+ 0·03	+ 0·09	8
22	2·3	1·21	1·21	0	0	4
29	2·4	2·32	2·30	− 0·02	+ 0·01	4
15	2·4	1·01	1·00	− 0·01	− 0·01	4
15	2·4	1·01	0·98	− 0·03	− 0·06	4
28	2·4	1·08	1·06	− 0·02	− 0·02	4
6	2·4	0·82	0·83	+ 0·01	+ 0·02	4
14	2·5	1·02	0·98	− 0·04	− 0·05	4
2	2·5	0·71	0·77	+ 0·06	+ 0·06	4
1	2·5	0·69	0·70	+ 0·01	0	4
8	2·6	0·90	0·87	− 0·03	− 0·03	4
6	2·6	0·82	0·80	− 0·02	− 0·02	4
6	2·6	0·82	0·80	− 0·02	− 0·01	8
1	2·6	0·69	0·70	+ 0·01	+ 0·01	4
2	2·6	0·71	0·74	+ 0·03	+ 0·06	8
18	3·4	1·13	0·95	− 0·18	− 0·16	4
28	3·4	1·08	1·00	− 0·08	− 0·17	8
15	3·4	1·01	0·91	− 0·10	− 0·11	4
14	3·4	1·02	0·89	− 0·13	− 0·15	4
2	3·4	0·71	0·67	− 0·04	− 0·03	4
1	3·4	0·69	0·67	− 0·02	− 0·03	4
1	3·4	0·69	0·67	− 0·02	0	8
2	3·4	0·71	0·69	− 0·02	− 0·04	8
21	3·4	0·55	0·58	+ 0·03	+ 0·04	8
25	3·4	0·02	0·06	+ 0·04	+ 0·03	4
21	3·6	0·55	0·57	+ 0·02	+ 0·05	8
20	3·8	0·44	0·51	+ 0·07	+ 0·07	10
19	4·1	0·19	0·36	+ 0·17	+ 0·21	8
19	4·9	0·19	0·27	+ 0·08	+ 0·13	8
20	5·0	0·44	0·43	− 0·01	− 0·02	4
20	5·0	0·44	0·43	− 0·01	− 0·02	8
19	5·2	0·19	0·24	+ 0·05	+ 0·08	4
6	5·4	0·82	0·69	− 0·13	− 0·15	4
1	5·4	0·69	0·61	− 0·08	− 0·08	4
19	5·6	0·19	0·20	+ 0·01	+ 0·06	8
25	5·7	0·02	0·02	0	+ 0·02	8
25	5·8	0·02	0·02	0	+ 0·01	6
19	5·8	0·19	0·16	− 0·03	0	8
19	6·4	0·19	0·13	− 0·06	− 0·03	8
25	7·2	0·02	0·01	− 0·01	+ 0·03	4
19	7·7	0·19	0·04	− 0·15	− 0·09	4

TABLE VII.—750° C.

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
14	4·2	1·02	1·09	+ 0·07	+ 0·10	7
23	4·6	1·58	1·64	+ 0·06	− 0·22 (?)	11
14	4·9	1·02	1·02	0	(?)	12
16	5·2	1·01	0·92	− 0·09	(?)	11
21	5·2	0·55	0·58	+ 0·03	+ 0·05	6
25	5·3	0·02	0·04	+ 0·02	0	4
23	5·4	1·58	1·56	− 0·02	+ 0·07	7
21	5·9	0·55	0·58	+ 0·03	+ 0·07	7
14	6·0	1·02	0·99	− 0·03	− 0·04	8
19	6·2	0·19	0·17	− 0·02	0	7
20	6·8	0·44	0·39	− 0·05	− 0·02	9

TABLE VIII.—710° C.

Steel.	Carbon Dioxide. Per Cent.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Change of Carbon Content. Per Cent.	Change of Weight. Per Cent.	Time of Heating. Hours.
22	6·7	1·21	1·29	+ 0·08	+ 0·08	6·5
21	7·6	0·55	0·58	+ 0·03	+ 0·06	7·0
7	8·0	0·85	0·88	+ 0·03	(?)	8·0
23	8·2	1·58	1·58	0	+ 0·05	6·5
19	8·2	0·19	0·25	+ 0·06	+ 0·01	6·0
19	8·4	0·19	0·31	+ 0·12	+ 0·10	8·0
21	8·6	0·55	0·50	− 0·05	− 0·06	6·5
7	8·8	0·85	0·82	− 0·03	− 0·05	7·0
19	8·8	0·19	0·20	+ 0·01	− 0·04	7·0
22	8·9	1·21	1·10	− 0·11	− 0·11	6·0
25	9·0	0·02	0·04	+ 0·02	− 0·10 (?)	8·0
21	9·5	0·55	0·41	− 0·14	− 0·06	7·0
19	9·5	0·19	0·14	− 0·05	− 0·06	7·0
25	9·7	0·02	0·03	+ 0·01	(?)	7·0
22	10·3	1·21	1·17	− 0·04	− 0·02	7·0
21	11·2	0·55	0·42	− 0·13	− 0·12	7·0

As may be seen from the tables, the changes in weight of the specimens generally agree well with the variation in carbon content, which shows that no oxidation reactions worth mentioning have taken place. Nor has any carbon precipitation or oxidation of the cuttings been observed.

Comparison and Discussion of the Experimental Results.

The horizontal lines to the left of Fig. 3 indicate the ferrite-austenite equilibrium of the lowest concentration; those to the

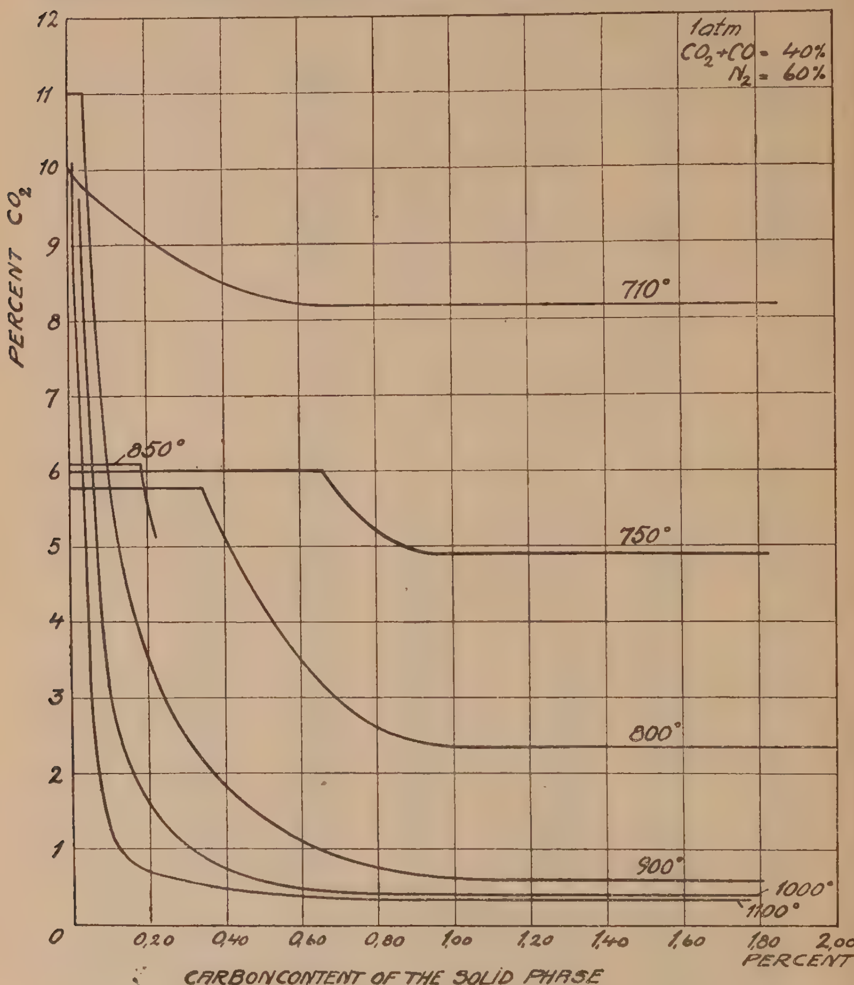

Fig. 3.

right give that of cementite-saturated austenite, and the curves between show the equilibria of austenite with varying percentages

of carbon. The isotherms for temperatures above point Ac3 for pure iron approach the ordinate axis asymptotically.

The strange fact may be noted at once that the isotherm for 710° C. bends upwards at a lower percentage of carbon instead of proceeding horizontally throughout its course. Theoretically the progress does not agree with the common view of the insolubility of carbon in ferrite below the Ac1 point; no conclusions should, however, be drawn from this single curve. It would be desirable, in addition, to determine the isotherm for a lower temperature, for instance 680° C., but time has not permitted of this.

Based on the isotherms in Fig. 3, a comparison has been made in Table IX. between the CO_2 content of the gas in equilibrium with the solid phases present at the temperatures in question. On plotting out the values given in this table in a diagram with the temperature as abscissæ and the gas composition as ordinates, the curve shown in Fig. 4 is obtained. For the sake of comparison the equilibrium curve $FeO + CO \rightleftarrows Fe + CO_2$ has also been drawn.

TABLE IX.

Temperature. Degrees C.	Solid Phases.	Per Cent. CO_2 in Fig. 3.	y. 0·4 atm.	x. 1 atm.	K_1.	K_3.	$\frac{K_1}{K_3}=\frac{[C_2]}{[C_3]}$
710	Ferrite-cementite	8·2	0·795	0·654	1·24	1·03	1·20
750	Ferrite-austenite	6·0	0·850	0·725	1·91	2·38	0·80
,,	Cementite-austenite	4·9	0·878	0·766	2·51	,,	1·05
800	Ferrite-austenite	5·75	0·856	0·734	2·03	6·19	0·33
,,	Austenite C = 0·40 per cent.	5·1	0·873	0·759	2·39	,,	0·39
,,	,, C = 0·60 ,,	3·5	0·913	0·822	3·80	,,	0·61
,,	,, C = 0·80 ,,	2·6	0·935	0·862	5·38	,,	0·87
,,	Cementite-austenite	2·3	0·945	0·875	6·13	,,	0·99
850	Ferrite-austenite	6·1	0·848	0·723	1·88	14·8	0·13
900	Ferrite-austenite	11·0	0·725	0·572	0·76	37·1	0·021
,,	Austenite C = 0·05 per cent.	9·0	0·775	0·629	1·06	,,	0·029
,,	,, C = 0·10 ,,	5·5	0·863	0·743	2·14	,,	0·058
,,	,, C = 0·20 ,,	3·5	0·913	0·822	3·80	,,	0·10
,,	,, C = 0·40 ,,	1·8	0·955	0·900	8·10	,,	0·22
,,	,, C = 0·60 ,,	1·1	0·973	0·934	13·2	,,	0·36
,,	Cementite-austenite	0·6	0·985	0·961	23·7	,,	0·64
1000	Austenite C = 0·05 per cent.	5·0	0·875	0·762	2·49	131	0·019
,,	,, C = 0·10 ,,	2·7	0·933	0·856	5·09	,,	0·039
,,	,, C = 0·20 ,,	1·6	0·960	0·909	9·08	,,	0·069
,,	,, C = 0·40 ,,	0·75	0·981	0·952	18·9	,,	0·14
,,	,, C = 0·60 ,,	0·5	0·988	0·967	28·3	,,	0·22
,,	Cementite-austenite	0·4	0·990	0·973	35·1	,,	0·27
1100	Austenite C = 0·05 per cent.	3·0	0·925	0·844	4·55	427	0·011
,,	,, C = 0·10 ,,	1·2	0·970	0·929	12·2	,,	0·029
,,	,, C = 0·20 ,,	0·7	0·983	0·956	20·8	,,	0·049
,,	,, C = 0·40 ,,	$\leqq$0·4	$\geqq$0·990	$\geqq$0·973	$\geqq$34	,,	$\geqq$0·080
,,	Cementite-austenite	$\leqq$0·3	$\geqq$0·993	$\geqq$0·978	$\geqq$44	,,	$\geqq$0·10

Below Ac1 (720° C.) a bivariant equilibrium is found, with ferrite and cementite as solid phases. Above this, two bivariant equilibria are found, given by the lines "ferrite-austenite" and "cementite-austenite," and between them an infinite number of equilibria for different percentages of carbon in the austenite, some of which are drawn in the figure. The ferrite-austenite curve asymptotically approaches the Ac3 temperature for pure ron. The different "lines of carbon percentages" intersect

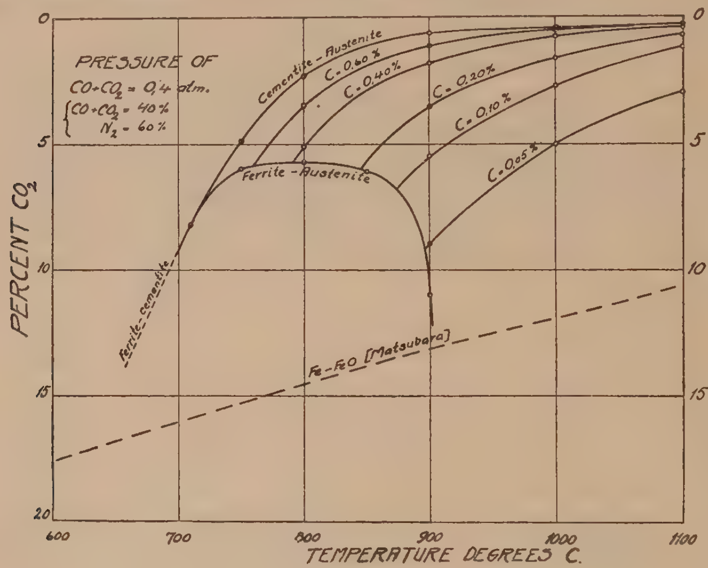

FIG. 4.

the ferrite-austenite line in points corresponding to the Ac3 temperature for the carbon contents in question; accordingly an iron-carbon diagram may be drawn from these curves, which is found to agree with that given in Fig. 1. It is also clear from Fig. 4 that when FeO is reduced above 900° C. the iron obtained must always contain some carbon, but when the reduction takes place below that temperature the product may be carbon-free iron.

In order to enable the results to be compared with the corresponding results of other investigators, the values given in Table IX. have been recalculated in the following manner to

a pressure of 1 atmosphere. The values given in the table correspond to a total pressure of $CO + CO_2 = 0{\cdot}4$ atmosphere, and for $CO + CO_2 = 40$ per cent.

If y and x denote the CO content of the gas at the pressures P_y and P_x, then $100y$ and $100x$ respectively correspond to the volume percentages of CO. The partial pressures of CO are then $y.P_y$ and $x.P_x$ respectively, and those of CO_2 $(1-y)P_y$ and $(1-x)P_x$. According to equation (1B) we obtain

$$K_1 = \frac{y^2}{1-y} \cdot P_y = \frac{x^2}{1-x} \cdot P_x;$$

$P_y = 0{\cdot}4$ atmosphere and $P_x = 1$ atmosphere, thus:

$$\frac{y^2}{1-y} \cdot 0{\cdot}4 = \frac{x^2}{1-x} \cdot 1.$$

According to Table IX. y is given, because $100(1 - y) = \frac{\text{per cent. } CO_2}{0{\cdot}4}$.

In Table IX. are given the calculated values of y and x as well as those of the equilibrium constant K_1 for reaction (1).

Fig. 5 represents the equilibrium curves, recalculated to a pressure of 1 atmosphere. For the purpose of comparison the equilibria of the reactions $FeO + CO \rightleftarrows Fe + CO_2$ and $Fe_3O_4 + CO \rightleftarrows 3FeO + CO_2$ have also been drawn, as well as the so-called "Boudouard's curve" $2CO \rightleftarrows C + CO_2$. The position of the latter, varying somewhat according to different investigators, has been determined according to the following formula, given by Tigerschiöld [2] with the aid of the very accurate values of Boudouard:

$$\log. K_3 = -\frac{8568}{T} + 3 \log. T - 0{\cdot}0007565\,(T - 600) + 0{\cdot}043,$$

where T is the absolute temperature.

The values so obtained, and recorded in Table X., agree satisfactorily with those obtained by Rhead and Wheeler [4] as well as with those of Schenck.[1]

The equilibrium of the reaction $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$ below 700° C., according to Schenck and his collaborators, included in Fig. 5, is of very great interest. Schenck, however, made no direct determinations, but calculated the equilibrium after having experimentally determined the equilibria $2CO \rightleftarrows C + CO_2$, $CH_4 \rightleftarrows C + 2H_2$ and $3Fe + CH_4 \rightleftarrows Fe_3C + 2H_2$. This mode of calculation is theoretically well founded, and it will

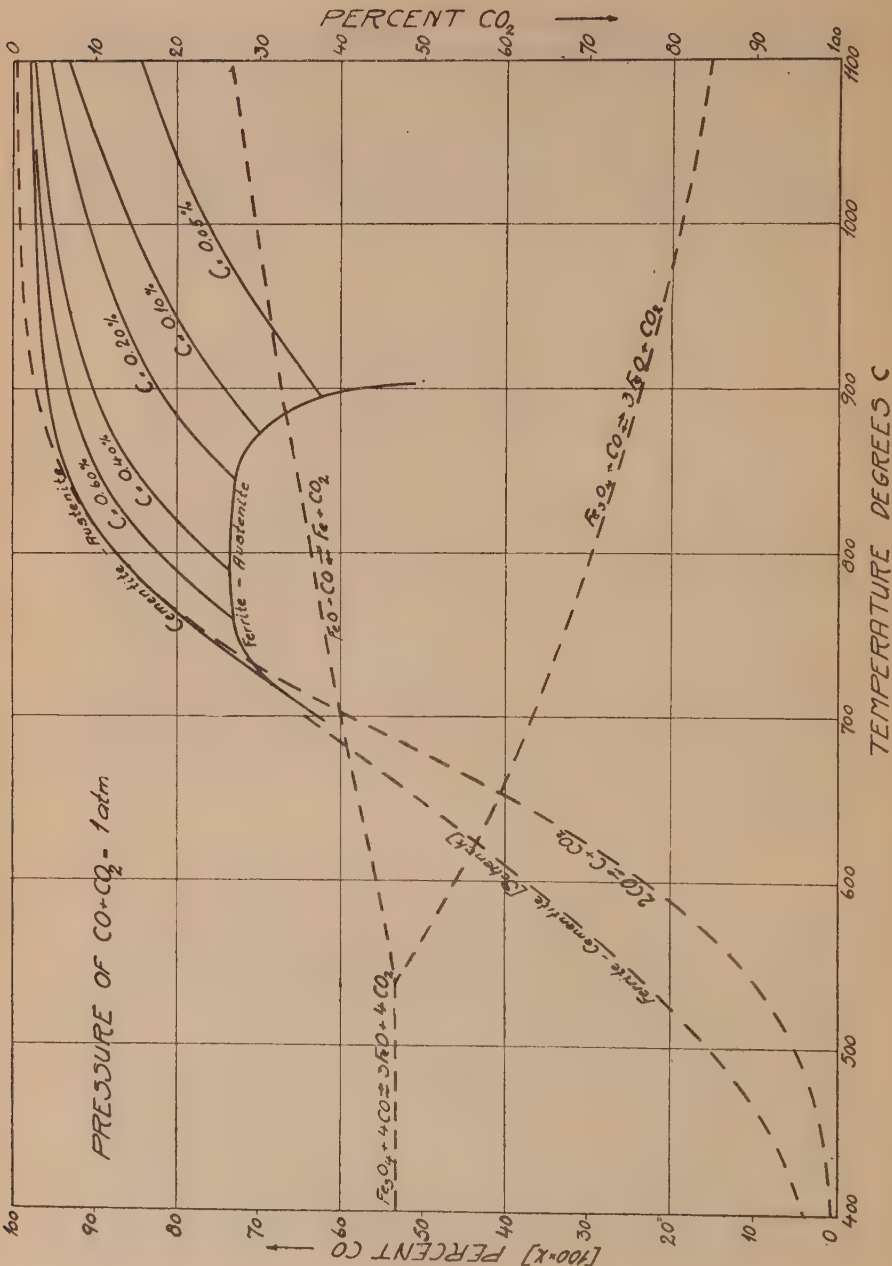
PERCENT CO2
TEMPERATURE DEGREES C
PRESSURE OF CO+CO2 - 1atm
PERCENT CO [100×X]
C, 0.05%
C, 0.10%
C, 0.20%
C, 0.40%
C, 0.60%
Austenite
Cementite
Ferrite - Austenite
FeO + CO ⇌ Fe + CO2
Fe3O4 + CO ⇌ 3FeO + CO2
Fe3O4 + 4CO ⇌ 3Fe + 4CO2
2CO ⇌ C + CO2
Ferrite - Cementite

Fig. 5.

be used later in an inverse direction. The diagram shows that Schenck's curve at 700° C. almost coincides with the curve of the present determinations; the displacement only amounts to about 5° laterally. This circumstance may be taken as good evidence of the accuracy of both these curves.

TABLE X.

Temperature. Degrees C.	Carbon Dioxide. Per Cent.	x.	K_3.	Carbon Dioxide: Determined by— Boudouard.	Schenck.	Rhead and Wheeler.
				Per Cent.	Per Cent.	Per Cent.
450	97·85	0·0215	0·000474	97·8	98·0	n.d.
500	94·6	0·054	0·0031	94·6	95·0	,,
600	76·8	0·232	0·070	76·8	n.d.	,,
700	41·3	0·587	0·83	41·3	41·0	,,
710	36·9	0·631	1·03	n.d.	n.d.	,,
750	14·1	0·759	2·38	,,	,,	,,
800	12·4	0·876	6·19	12·4	13·9	,,
850	6·0	0·940	14·8	n.d.	n.d.	6·23
900	2·55	0·9745	37·1	2·9	,,	2·22
1000	0·75	0·9925	131	0·9	,,	0·59
1100	0·20	0·998	427	n.d.	,,	0·15

n.d. = not determined.

Schenck in his investigations on the cementation of iron with CH_4 has so far not used temperatures higher than about 700° C. Nor have his attempts to determine directly the equilibrium $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$ given any consistent results. Instead, working on certain theoretical principles, he has tried to construct equilibria for higher temperatures, which, however, do not agree with those experimentally determined now. On this account, there seems to be no reason for a closer consideration of Schenck's theory, which, as pointed out by Matsubara,(3) must tend to a wrong direction. It should, however, be especially noted that the carbon pressure of cementite is not always greater than that of the elementary carbon, as postulated by Schenck; this is valid only below about 800° C., whilst above that temperature the carbon pressure of cementite is the lower, as may be seen later on.

A second determination of the equilibrium $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$ was made by Matsubara.(3) His equilibrium curve

had about the same direction as the curve in Fig. 5 indicating the equilibrium of cementite-saturated austenite; the x values, however, presented considerable deviations, as is shown by the following figures:

Temperature. °C.	$x \left(= \frac{\text{per Cent. CO}}{100}\right)$ Cementite-Austenite.	At 1 Atm. According to Matsubara.
750	0·766	0·783
800	0·875	0·866
900	0·961	0·917
1000	0·973	0·951
1100	0·978	0·981

It may be pointed out that Matsubara did not determine the composition of the solid phase, but drew conclusions as to the setting in of one or other of the equilibria from the change in the gaseous phase, a procedure which is certainly apt to involve errors.

Finally, a few words may be mentioned on the fundamental factor of the reaction, *i.e.* the carbon pressure of cementite and solid solutions. As shown by equation (4), these carbon pressures stand in the same relation to that of the elementary carbon as the equilibrium constant K_1 to K_3, *i.e.*

$$\frac{[C_2]}{[C_3]} = \frac{K_1}{K_3}.$$

As K_1 and K_3 are known from Tables IX. and X. respectively, the desired relation may be calculated, which is done in Table IX.

If, according to these numbers, isotherms of the carbon pressure are drawn as functions of the carbon content in the solid phase, the curves shown in Fig. 6 will result. $[C_3]$ is constant for each temperature, the curves thus giving $[C_2]$ as a pure function of the carbon content at each temperature respectively. This function is found to be almost rectilinear for the solid solutions, *i.e.* the carbon pressure of austenite increases in proportion to its carbon content. Consequently the carbon pressure seems to follow the same law as the osmotic pressure of a solution.

The carbon pressure of cementite does not increase with increasing temperature as quickly as that of austenite, and it

therefore results that the higher the temperature, the lower the carbon content of austenite, where its carbon pressure almost amounts to that of cementite. An equal carbon pressure is not reached until the austenite is saturated with carbon. As an instance may be taken the isotherm at 1000° C., where it must be presumed that the curve of the carbon pressure of austenite

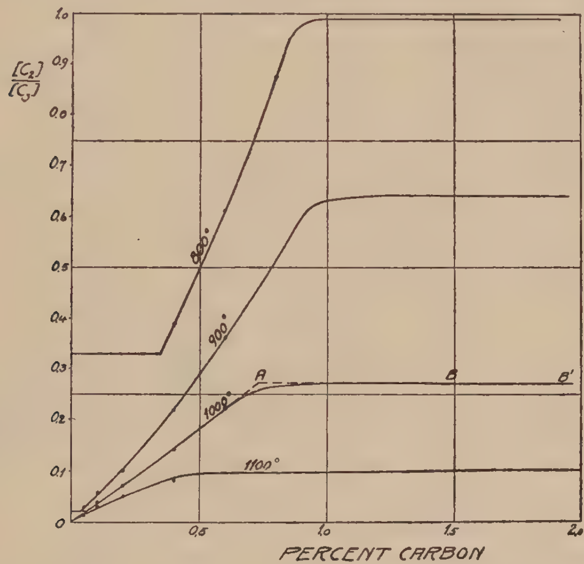

FIG. 6.

bends before point *A* is reached, passing into the cementite line first at the point *B*.

Fig. 7 gives the relation of the carbon pressure as a function of the temperature. Thus below the line 1·0 the carbon pressure of cementite and solid solutions is lower than that of carbon ; above 1·0 the opposite is the case. An atmosphere of CO and CO_2 in equilibrium with elementary carbon is therefore unable to carburise the iron until about 735° C. (point *A*), when austenite with about 0·7 per cent. carbon is formed. The carbon content of the austenite is increased with a rising temperature, but no free cementite is formed until about 790° C. (point *B*). Below 735° C. decarburisation always takes place in such an atmosphere

(a steel with an excess of cementite is already decarburised at 790° C.), clearly proving the risk of surface decarburisation on annealing steel in the presence of charcoal. The points *A* and *B* in Fig. 7 correspond with the intersection points of Boudouard's

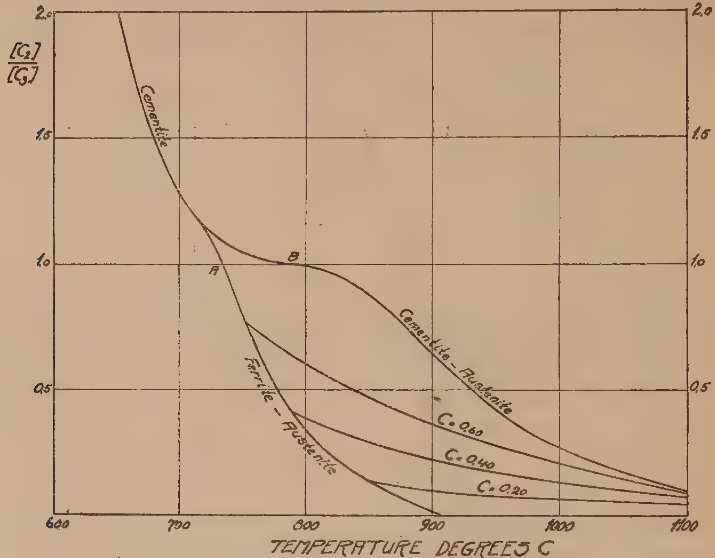

Fig. 7.

curve, and the lines "ferrite-austenite" and "cementite-austenite" respectively in Fig. 5. The position of the intersection points is constant and independent of the pressure of the gaseous phase.

2. Decarburisation in Hydrogen.

Literature.—The decarburisation of iron in hydrogen has been the subject of many investigations. Nevertheless, up till quite lately, opinions seem to have differed whether in reality hydrogen has any decarburising influence on iron or not. Cementation by means of hydrocarbons is a process which has for a long time been of practical importance, but the reverse action is considered by several investigators as improbable, at least at temperatures which are not too high. The question has lately been discussed

on several occasions in the publications of this Institute, and consequently the following summary of literature may be made very short.

The first research emanated from Forquignon [5] in 1881, who, on heating a pig-iron in dry, pure hydrogen at a bright red heat, noted a considerable volatilisation of the carbon. The gases thus formed did not contain any CO_2, CO, or acetylene, but, on the contrary, another hydrocarbon, which Forquignon considered to be methane. On the other hand, Wüst and Geiger [6] could not observe any decarburisation of pig-iron at a temperature of 900° to 1100° C., whereas Charpy [7] obtained confirmation of Forquignon's results. Repeated experiments made by Wüst and Sudhoff,[8] including several heatings at a temperature of 1000° to 1050° C. for periods up to forty-eight hours, still failed to reveal any decarburisation, as was the case with the researches of Emmons.[9] The latter heated round bars of crucible steel with 1·15 per cent. carbon, some at a temperature of 983° C. for three hours, others at 1166° C. for six hours. On examining microscopically the heated bars, however, he found a cementite network reaching to the very edge, and, consequently, he inferred that no decarburisation had taken place. On the other hand, Schmitz [10] found very strong decarburisation, when heating cuttings of different kinds of steel in pure hydrogen at a temperature of 1100° to 1200° C. He also succeeded in decarburising molten pig-iron and in volatilising pro-eutectic graphite in hydrogen at 1100° C.

Several more systematic investigations have later been published in the *Journal of the Iron and Steel Institute.* Campbell [11] heated 6-millimetre square bars of different kinds of steel, and found, among other things, that the hydrogen decarburised most quickly at 950° to 1000° C., that moist hydrogen acted more strongly than dry gas, and further that a steel bar of given dimensions was entirely decarburised in about five days. Different kinds of steel showed a varying disposition for decarburisation; pure carbon steel, nickel and tungsten steels decarburised at about the same rate, manganese steel and chromium steel somewhat slower. In the discussion on that paper Le Chatelier expressed the opinion that, when heating steels with different percentages of carbon in a mixture of hydrogen

and methane, it would probably be found that the same gas would be able to carburise soft iron and decarburise hard steel. This was also confirmed by a research of Whiteley,[12] who placed a piece of steel and a piece of Armco iron close together in a tube furnace and heated them in a slow current of dry hydrogen at 1050° C. He then found a distinct decarburisation of the steel, and simultaneously a carburisation of the iron. The latter was evidently due to the hydrocarbons formed by the decarburisation of the steel. A still better proof of Le Chatelier's hypothesis was later given by Campbell, Fink and Ross,[14] who bundled a number of bars (6 millimetres square by 150 millimetres long) of steel and iron, so that they were held at a distance of about 0·2 millimetre from each other. The bundle was put into a tube furnace, which was then filled with dry hydrogen and heated to 950° to 960° C. for seven days, during which time a low pressure of hydrogen (no gas current) was maintained in the furnace. After the experiment it was found that the steel, which originally contained 1·39 per cent. carbon, had been decarburised to 0·73 per cent. carbon, while the soft iron had been carburised to 0·70 per cent. carbon. Unfortunately the composition of the gas mixture in the furnace was not determined, otherwise a determination of the ratio of the equilibrium might have been obtained. The same authors [15] showed by other experiments that the chromium carbides were considerably more difficult to decarburise with hydrogen than the iron carbide. A bar, 6 millimetres square, of stainless steel, with 0·23 per cent. carbon and 14·32 per cent. chromium, after having been heated in moist hydrogen at 950° to 1000° C. for five days, showed no decarburisation whatever, while a steel with 0·85 per cent. carbon and 2·33 per cent. chromium under identical circumstances was decarburised to 0·04 per cent. carbon. A cemented bar with 1·18 per cent. carbon was decarburised in eight days to 0·005 per cent. carbon. Comparing the action of dry and moist hydrogen, the authors found the decarburising effect of the latter to be much more powerful. Another paper by Austin [13] dealt principally with the question of the surface decarburisation of steel in hydrogen, and will therefore be mentioned in connection with this question.

The conclusive proof of the reversibility of the reaction $Fe_3C + 2H_2 \rightleftharpoons 3Fe + CH_4$ seems to have been given by Schenck [1]

and his collaborators, who determined the equilibria for the reaction below 720° C., as previously mentioned. It should, however, be pointed out that there does not as yet exist any proof that the hydrocarbon which is formed during the decarburisation of iron with hydrogen at higher temperatures is in reality methane. It is also possible to imagine the formation of other hydrocarbons. It might, however, for the present, be convenient to take only the methane equilibrium into consideration.

The equilibrium $Fe_3C + 2H_2 \rightleftarrows 3Fe + CH_4$.—As mentioned above, the researches by Schenck were limited to temperatures below 720° C., but from the known equilibrium $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$ it is possible to calculate the above equilibrium. If, as before, we assume the reaction—

$$Fe_3C + 2H_2 \rightleftarrows 3Fe + CH_4 \quad . \quad . \quad . \quad . \quad (5)$$

to take place in the following two stages:

$$C + 2H_2 \rightleftarrows CH_4 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

and

$$Fe_3C \rightleftarrows 3Fe + C \quad . \quad . \quad . \quad . \quad . \quad (2)$$

we obtain the dissociation constant of methane,

$$k_6 = \frac{[C_6] \cdot [H_2]^2}{[CH_4]}$$

or the equilibrium constant for reaction (6),

$$K_6 = \frac{[H_2]^2}{[CH_4]}, \text{ where } K_6 = \frac{k_6}{[C_6]}.$$

For reaction (5) we obtain with corresponding notations:

$$k_5 = \frac{[C_5] \cdot [H_2]^2}{[CH_4]}$$

or

$$K_5 = \frac{[H_2]^2}{[CH_4]}, \text{ where } K_5 = \frac{k_5}{[C_5]}.$$

Now, for a certain temperature we may, however, write—

$$k_5 = k_6, \ [C_6] = [C_3], \text{ and } [C_5] = [C_2] \ (cf. \text{ p. } 298),$$

wherefrom is obtained—

$$\frac{K_6}{K_5} = \frac{[C_2]}{[C_3]} = \frac{K_1}{K_3} \text{ (see p. 298)};$$

consequently,

$$K_5 = K_6 \cdot \frac{K_3}{K_1} = \frac{[H_2]^2}{[CH_4]} \text{ for the equilibrium (5).}$$

K_1 and K_3 can be derived from Table IX.; for the constant K_6 of the so-called methane equilibrium there are, however, no experimental determinations above 740° C. The efforts of the authors to set up a thermo-dynamic formula for K_6 have led to no results agreeing with the values found by Schenck [1] and Mayer and Altmayer.[16] We are therefore only able to give a qualitative account of the equilibrium curves at higher temperatures, which is done in Fig. 8. The reaction $C + 2H_2 \rightleftarrows CH_4$ has been supposed to proceed along the dashed line, and in this case the other curves will lie in the positions indicated. If future investigation should show that the methane equilibrium is displaced towards higher or lower methane percentages, the other curves will be displaced in the same proportion, but it ought to be observed that all intersection points between the curves are fixed with regard to the temperature. Likewise the "ferrite-austenite" line will always end in a fixed point corresponding to $CH_4 = 0$ per cent., and the temperature = A3 for pure iron. The intersection points of the curves are situated at the same temperatures as the corresponding points in Figs. 5 and 7, as they are dependent only on the carbon pressures of the different solid phases. The same cementation and decarburisation conditions prevail as previously mentioned for a CO–CO_2 atmosphere. The remarkable fact of the small methane percentage, which at a temperature of 900° to 1000° C. suffices to destroy the decarburising influence of hydrogen on iron, should be noted.

It is interesting to compare these results with the equilibrium curves recently published by Schenck.[1] Schenck also found the intersection point between the carbon, hydrogen, and methane equilibrium curve and the ferrite-austenite line, though it was situated at about 720° instead of 730° to 735° C. as now found. He considers, however, that the ferrite-austenite line should continue asymptotically towards the abscissa-axis, which according to the above is incorrect, as it ends in a fixed point on this axis. Likewise, the cémentite-austenite line was drawn incorrectly, on account of Schenck having started from the point of view that the carbon pressure of the cementite must always be greater than that of the elementary carbon. The experimental data concerning the carbon pressure of cementite below 720° C. which have been determined by Schenck appear, however, to

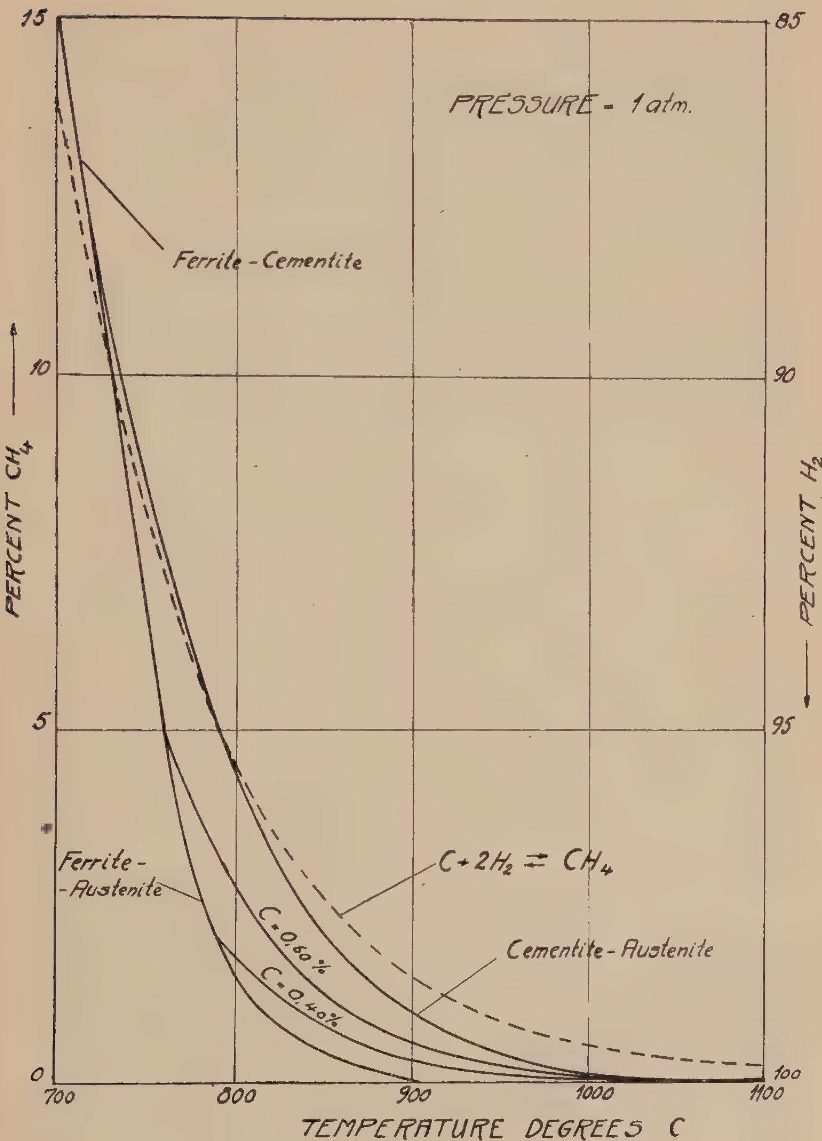

Fig. 8.

agree well with those now found, as was previously pointed out.

An experimental determination of the above-mentioned equilibria was originally included in the plan of the investigation, an apparatus having also been constructed for the purpose. As, however, time has not permitted the employment of this apparatus, the following tests, which have an important bearing on the question of the surface decarburisation of steel, were made instead.

Experiments.—In the experimental arrangement used, the hydrogen, which was produced by the electrolysis of distilled water mixed with caustic soda, was taken from a cylinder furnished with a needle-valve to permit the regulation of the speed of the gas current. It was first dried with concentrated sulphuric acid, and then, to purify the gas from oxygen, it was passed through a glass tube with palladinised asbestos electrically heated to about 300° C. The water formed was absorbed by caustic soda, calcium chloride, and phosphorus pentoxide. In order to ascertain that the gas was then free from oxygen, it was passed through still another heated tube with palladinised asbestos, and then through a removable U-tube containing phosphorus pentoxide. If, before entering the second heated tube, the gas were entirely free from oxygen, the U-tube would not show any increase in weight. Weighings were made now and then which showed an increase of weight of about 1 milligramme in fifty hours, which was considered to be quite satisfactory. The hydrogen, thus purified, was then admitted into the furnace, which was arranged in exactly the same way as described in Section 1.

The experiments included the heating in a current of pure hydrogen of thin cuttings of different kinds of steels at varying temperatures and for various periods. For each test 3 grammes of cuttings were weighed into a magnesia boat as described above. As it was expected that the speed of the gas current would influence the intensity of the decarburisation by the more or less rapid removal of the hydrocarbons formed, some experiments were made at a temperature of 1050° C. to ascertain the gas speed beyond which no increase in the decarburisation was obtained. This speed was found to be about 200 bubbles per minute, corresponding to about 2 litres of gas per hour, on account of which all tests were made with this gas velocity.

It was further anticipated that the cuttings at the top of the boat might be decarburised to a greater degree than those lying at the bottom. Two tests were therefore made on samples of the cuttings from the surface and underneath, after decarburising a steel with an original carbon percentage of 1·13. One test gave a carbon percentage of the surface cuttings of 0·50, of the bottom cuttings of 0·51; for the other test the figures were 0·34 and 0·35 per cent. respectively. Consequently there was no irregularity worth mentioning.

The first series of tests consisted in heating first a series of pure carbon steels at a constant temperature of 1050° C. for various periods. The results are tabulated in Table XI. and are illustrated graphically in Fig. 9. (For analyses of the steels,

TABLE XI.—*Temperature*, 1050° *C.*

Steel.	Time of Heating. Hours.	Carbon. Per Cent. Before.	Carbon. Per Cent. After.	Remarks.
18	16	1·13	0·35	Carbon steel
18	8	1·13	0·58	,,
18	4	1·13	0·78	,,
15	16	1·01	0·32	,,
3	16	0·72	0·27	,,
26	24	0·42	0·10	,,
26	16	0·42	0·15	,,
26	16	0·42	0·14	,,
26	8	0·42	0·24	,,
26	4	0·42	0·33	,,
30	16	0·39	0·09	Si = 1·75 per cent.; Mn = 0·61 per cent.
32	16	0·56	0·21	Mn = 2·02 ,,
33	16	0·83	0·28	Ni = about 2·0 per cent.
34	16	0·63	0·24	W = ,, 2·0 ,,
36	16	0·43	0·17	Cr = 0·85 per cent.; Ni = 2·18 per cent.
31	16	1·03	0·44	Cr = 1·61 per cent.
38	16	1·06	0·43	Cr = 1·29 ,,
38	16	1·06	0·45	Cr = 1·29 ,,
37	16	1·03	0·39	Cr = about 1·5 per cent.
39	16	0·42	0·36	Cr = ,, 14·0 per cent., stainless
39	16	0·42	0·38	Cr = ,, ,, ,,
39	16	0·42	0·37	Cr = ,, ,, ,,

see Table I.) The curve gives the decarburisation of carbon steels as a function of the time. From this it may be seen that when a steel of, say, 0·58 per cent. carbon is heated for eight

hours, the carbon content will within this time decrease to 0·35 per cent., in sixteen hours to 0·21 per cent., and in twenty-four hours to 0·13 per cent.

The same tests were then made with silicon, manganese, tungsten, chromium, nickel, and chromium-nickel steels, in order to ascertain the influence of the alloyed elements on the speed of decarburisation. The points marked in Fig. 9 correspond with

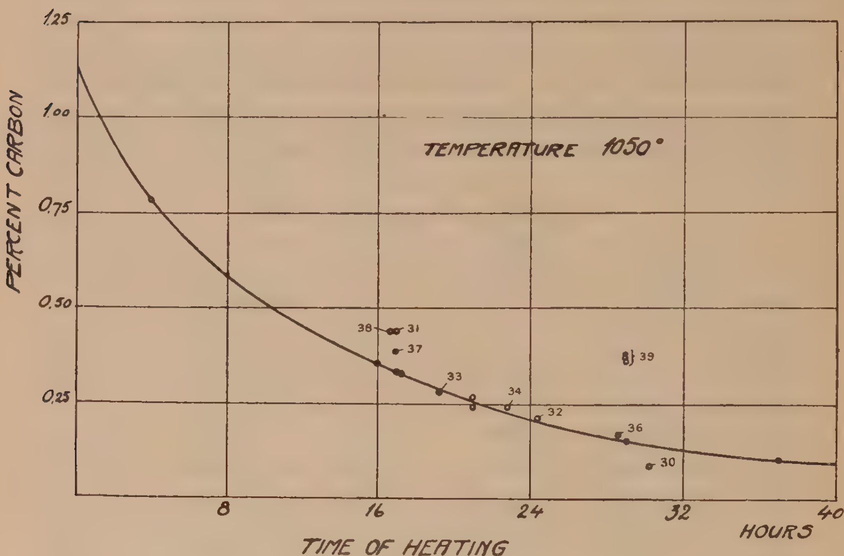

Fig. 9.

the index numbers of the test specimens according to Tables XI. and I. It will be noted from this that the manganese, nickel, tungsten, and chromium-nickel steels show about the same tendency to decarburise as the pure carbon steels, the percentage of the alloyed element in several cases, however, being rather low. The silicon steel shows, on the other hand, stronger decarburisation, and the chromium steel considerably less. The stainless steel (No. 39) decarburised in sixteen hours from 0·42 down to about 0·37 per cent. only, but an ordinary carbon steel would, under the same conditions, have decarburised to about 0·15 per cent. carbon. Even an ordinary ball-bearing steel

decarburises considerably less than a carbon steel with the same carbon content.

The second series of tests aimed at discovering the degree of dependence of the decarburising speed on the heating temperature. The specimens were therefore heated for a constant period of sixteen hours, and at temperatures varying between 600° and 1150° C. As test material were used two carbon steels (Nos. 18 and 3) with 1·13 and 0·72 per cent. carbon respectively, as well as a ball-bearing steel (No. 38) with 1·06 per cent. carbon and 1·29 per cent. chromium. Further, some tests were made on a soft silicon steel (No. 30) with 0·39 per cent. carbon, 1·75 per cent. silicon, and 0·61 per cent. manganese. The results are to be found in Table XII. and Fig. 10.

TABLE XII.—*Time of Heating, Sixteen Hours.*

Steel.	Temperature. Degrees C.	Carbon. Per Cent.	
		Before.	After.
18	600	1·13	1·11
,,	635	,,	1·09
,,	680	,,	1·02
,,	725	,,	0·89
,,	755	,,	0·77
,,	800	,,	0·59
,,	850	,,	0·39
,,	900	,,	0·31
,,	945	,,	0·27
,,	1050	,,	0·35
,,	1150	,,	0·37
3	600	0·72	0·71
,,	670	,,	0·61
,,	750	,,	0·29
,,	850	,,	0·16
,,	940	,,	0·14
,,	1050	,,	0·27
,,	1150	,,	0·16
,,	1150	,,	0·12
38	650	1·06	1·05
,,	740	,,	0·92
,,	770	,,	0·85
,,	950	,,	0·32
,,	1050	,,	0·43
,,	1150	,,	0·39
30	725	0·39	0·33
,,	860	,,	0·07

The decarburisation is already apparent at about 600° C., and then increases very quickly above 650° to 700° C., reaching a maximum at about 950° C. The decarburisation speed is evidently less at 1050° C. than at 950° C., but it appears to increase again at higher temperatures. It is difficult to explain the reason for this rather peculiar course of the curves, as the decarburisation speed is dependent on many factors, as, for

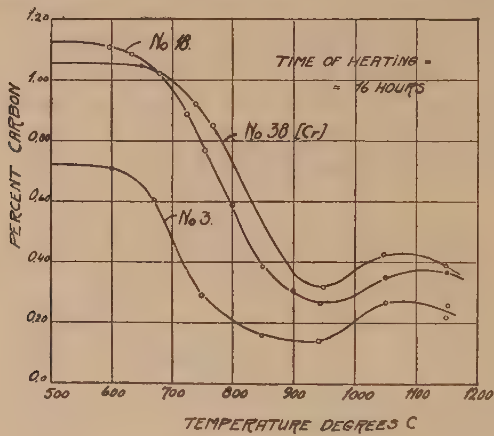

Fig. 10.

instance, on the equilibria of the reaction, on the reaction speed as well as on the diffusion speed of the carbon and the hydrogen in the iron. The course, however, corresponds with the observation by Campbell,[11] previously referred to, that hydrogen decarburises most rapidly at 950° to 1000° C. Fig. 10 also shows clearly the slighter disposition of chromium steels to decarburise in comparison with pure carbon steels.

3. Decarburisation in Nitrogen.

Literature.—The decarburising influence of pure nitrogen on iron has in general been studied by the same investigators who have examined the corresponding conditions with hydrogen. The first experiments in this matter were likewise made by Forquignon,[5] who heated pig-iron in pure nitrogen and found a considerable decarburisation. As he supposed the carbon to be

removed as cyanogen, he repeated the test and directed the gases from the furnace through caustic potash solution in order to absorb the cyanogen. The sample was first heated in a steady stream of nitrogen for seventy hours at a dark red heat, without, however, any cyanogen appearing. The temperature was therefore increased to a bright red heat (*rouge très vif*) for forty-eight hours. A reaction for cyanogen in the caustic potash solution was then obtained by the precipitation of Prussian blue.

Against this Wüst and Geiger (6) found no decarburisation when pig-iron was heated in carefully purified nitrogen at 900° to 1100° C. during five to twelve hours, which was also confirmed by later tests made by Wüst and Sudhoff,(8) nor could they confirm the formation of cyanogen. Consequently they concluded that the decarburisation obtained by Forquignon was due to an insufficient purification of the nitrogen from oxygen and moisture. Schmitz,(10) who did not succeed in producing pure nitrogen, arrived at the same conclusion.

However, Oberhoffer and Heger (17, 18) consider that they have confirmed Forquignon's observation of the decarburising action of nitrogen. When a steel was heated at 1200° C. for twenty-three hours, they found a decrease in the percentage of carbon from 0·80 to 0·69, and the same test continued for seventy-three hours showed a decrease from 0·80 to 0·51 per cent. The nitrogen, which was supplied from a cylinder, was freed from oxygen by being first passed through a pyrogallic solution, then over glowing copper, and finally over soft iron chips at a temperature of about 700° C. But the further means adopted for the purification of the nitrogen were, however, open to criticism, and it is probable that their results may be attributed to defective purification arrangements.

Experiments.

In fact a study of the literature shows that the chief difficulty in the performance of these experiments lies in ensuring an absolutely complete purification of the nitrogen. In our method for carrying out this operation, the nitrogen was produced by the fractional distillation of liquid air, and contained about 3 to 4 per cent. oxygen. It was admitted from a cylinder into

a gasometer system, consisting of two 10-litre glass bottles. From here it was first allowed to pass to a wash-bottle containing a 10 per cent. silver nitrate solution for the absorption of any hydrogen sulphide or phosphide which might be present, and then to another wash-bottle containing a 35 per cent. caustic soda solution for the removal of carbon dioxide. Afterwards it was dried by means of concentrated sulphuric acid in bulb-tubes, and calcium chloride and phosphorus pentoxide in a U-tube. The bulk of the oxygen was removed in a furnace by means of a fine copper gauze, which was kept at a temperature of 700° to 750° C., after which the gas was further dried in another U-tube. The oxygen still remaining in the gas was finally removed in a second furnace by means of cuttings of electrolytic iron, freed from carbon, and heated to a temperature of about 800° C. It is important that the iron should be entirely free from carbon, as otherwise the oxygen forms carbon monoxide and carbon dioxide, which would be present as impurities in the nitrogen. The electrolytic iron, which originally contained about 0·02 per cent. carbon, was therefore heated for a long time first in moist and then in dry hydrogen, before use. After leaving the second furnace the gas was dried once again by means of phosphorus pentoxide, and was then considered to be entirely pure and ready for use. The arrangements for heating the sample in the testing furnace were the same as previously described in Section 1. All connections after the removal of the bulk of the oxygen were made with vacuum wax, as caoutchouc connections were considered likely to admit oxygen from the air.

The gas was tested for any remaining trace of oxygen by heating cuttings of carbon-free electrolytic iron for several hours in a current of the gas at a temperature of about 1000° C. The cuttings showed no trace of being oxidised. Likewise the gas was tested for freedom from carbon dioxide, carbon monoxide, and hydrogen by combustion with pure oxygen, and attaching absorbing vessels for carbon dioxide and water. No increase in weight could be detected.

The first trials were intended as a retesting for the formation of cyanogen found by Forquignon. For this purpose samples of both pig-iron and steel were heated for ten to twenty hours at a temperature of 1050° C., the nitrogen being admitted at a

speed of about 1 litre per hour. The samples, which consisted of small pieces of pig-iron or of milled steel cuttings, were placed in a magnesia boat. The gases escaping from the furnace were passed through a bulb-tube containing a solution of NaOH and $FeSO_4$. After the test the solution was boiled and acidified with hydrochloric acid, whereby Prussian blue would form, if any cyanogen were present. (Other reagents were also tested by means of gases containing cyanogen, but this one appeared to be the most reliable.) All the tests, however, gave an entirely negative result, and it was not possible to discover any trace of formation of cyanogen.

In several subsequent tests it was tried gravimetrically to determine the gases given off from the steel, which should have consisted of H_2O, CO_2, CO, H_2, and possibly CH_4, by allowing the gases from the furnace to pass through a series of absorption and combustion apparatus, which was, however, very complicated, and owing to the long testing periods (up to sixty-five hours) we did not succeed in reducing the blank tests of the apparatus so far as to be able to render any positive determinations possible.

The percentage of carbon in the samples was determined before and after heating. It was then found that the decarburisation amounted to 0·01 to 0·03 per cent., which we consider principally to be attributable to the influence of gases and oxide inclusions in the steel.

II. THE SURFACE DECARBURISATION OF STEEL.

Many different factors co-operate in the phenomenon known as the "surface decarburisation of steel." The first condition for decarburisation to take place, *i.e.* that the surrounding gas must have a decarburising influence, is evident from the foregoing. Another factor of great importance is the speed of reaction, which is dependent not only on the temperature, but also on the deviation of the composition of the gas from that which it would have when in equilibrium, so that the higher the CO_2 or H_2 percentage is, the greater the reaction speed becomes. The reaction between the gas and the cementite or the austenite obviously takes place in the outer layers of the solid steel piece,

without, however, necessarily taking place at the surface itself, as the gases may be supposed to have a certain power of diffusing in the iron. The outer layer, which is then decarburised, strives again to absorb carbon from the inner parts of the steel piece by diffusion of the carbon in solid solution. The diffusion speed of this carbon naturally varies considerably at different temperatures, and the decarburised zone may thereby vary in character according to the temperature. Experience has also proved that the formation of an oxide scale on the surface of the steel considerably influences the course of the decarburisation, though the reason for this is not quite clear.

Consequently the occurrence of surface decarburisation on annealing steel, or on heating it prior to working, principally depends on the following factors:

(1) The equilibria of the carburisation and decarburisation of the iron.
(2) The speed of the reaction.
(3) The power of diffusion of the gases in the iron.
(4) The speed of diffusion of the carbon in the iron.
(5) The formation of an oxide scale.

The intention of the present investigation was to ascertain, in the first place, the combined effect of these different factors, which are all dependent on the temperature, when steel is heated in various gases and at varying temperatures.

Literature.—One of the most important investigations regarding the surface decarburisation of steel on heating in various gases is that of Emmons,[9] who heated small test-cylinders of a tool-steel with 1·15 per cent. carbon for a constant period of three hours in different gases and at varying temperatures. The decarburisation was measured microscopically from the surface to that point where free cementite appeared, this being easier to determine than the point at which decarburisation really begins. The gases consisted of pure dry hydrogen, carbon dioxide, oxygen, and air. As previously mentioned, it was not possible to observe any decarburisation in hydrogen. With the other gases no decarburisation was obtained below Ac1, but Emmons considers that the carbon must form a solid solution with the iron in order to permit of its oxidation, and that the depth of

decarburisation is principally dependent on the speed of diffusion of the carbon. To summarise the results of Emmons' investigations it may be stated that he found that steam had the strongest decarburising effect, next carbon dioxide, and finally air and oxygen. Emmons also showed that steel is decarburised when heated in charcoal at about 780° C. (*cf.* p. 319) (which was also noted by Greenwood [20]), and also when heated in a lead bath, containing Pb_2O.

Scott [21] examined the formation of oxide scale and the de carburisation on heating in air in an electric muffle. The steel, which originally contained 0·86 per cent. carbon, was decarburised for various periods at different temperatures. Scott specially points out the influence of scale formation on surface decarburisa tion. Thus, below 850° C. he found scarcely any decarburisation, due to the fact that the scale formation proceeded at the same rate as the decarburisation. A soft iron showed a greater formation of scale than the steel. It is also pointed out that the depth of decarburisation is not identical with the degree thereof. Heating for half an hour at 1060° C. gives the same depth as that obtained in one hour at 970° C., but in the latter case a considerably smaller quantity of free ferrite is observable.

Another interesting investigation concerning the decarburisation conditions on heating in air has been made by Schulz and Niemeyer.[22] They summarise their results as follows: (1) No difference occurs between planed, ground, and polished specimens; for a constant heating period the depth of decarburisation increases in proportion to the temperature; at the same temperature the decarburisation speed is greatest at the beginning of the heating; in a eutectoid steel incipient decarburisation is apparent already at 700° C. after two hours.* (2) The eutectoid steel always decarburises deepest, and a hypo-eutectoid steel deeper than a hyper-eutectoid one below 1000° C., but at 1100° C. the reverse is the case. (3) Silicon and tungsten steels show a distinct decarburisation at 800° C., differing in this respect from the chromium and manganese steels, which show no trace of decarburisation until 900° C. (the steels contained 1·58 per cent. silicon, 0·90 per cent. tungsten, 1·43 per cent. chromium,

* Not, however, measurable and chemically determinable until treated at 800° C. for two hours.

and 1·06 per cent. manganese respectively; the carbon percentage was 0·93 to 1·17). At 1000° C. the chromium steel showed a decarburisation of 0·06 millimetre; the manganese steel, 0·2 millimetre; silicon and eutectoid carbon steel, 0·3 millimetre; and tungsten steel, 0·4 millimetre. At 1100° C. the decarburisation of the chromium steel increased more rapidly in proportion to the other steels. Consequently, tungsten should promote the decarburisation, manganese and chromium should reduce it, while silicon should exert no influence at all.

Austin[(13)] has made a series of decarburisation tests in moist hydrogen, showing clearly how the diffusion speed of the carbon influences the character of the decarburised zone. The tests were made with 10-millimetre round bars of three different steels containing 0·40, 0·99, and 1·27 per cent. carbon respectively, the bars being heated for six to twelve hours in a current of moist hydrogen. At 680° C. and 755° C. a thin layer of ferrite was seen distinctly separate from the unchanged material; at 850° C. the limit was less pronounced, and at 1000° C. an almost pure ferrite layer was obtained at the edge, but inside it was a zone containing a steadily increasing percentage of carbon. The formation of a layer free from carbon consequently depends on the relation between the diffusion of the hydrogen into the iron on the one hand and on the diffusion speed of the carbon towards the surface on the other. Austin's curves, showing the dependence of the decarburisation depth on the temperature during a twelve-hour heating, and on the time of heating at 680° C., make it evident that the power of diffusion of the hydrogen regulates the courses of the curves. In connection with these tests Austin has also examined the decarburisation power of dry hydrogen, which proved to be considerably less. Thus at 850° a ferrite layer could not be obtained until after a heating period of twenty-five hours.

Austin's investigation on the diffusion speed of carbon in iron is also very interesting. For this purpose a 5-millimetre round bar of the steel containing 1·27 per cent. carbon was heated in moist hydrogen at 680° C. during one hundred hours, so that a pure ferrite layer and an unchanged core were obtained. The bar was divided into smaller pieces, which were then heated *in vacuo*. Below Ac3 the diffusion of the carbon was very slow;

at 920° C. and after six hours the core was freed from cementite and the carbon had proceeded half-way towards the surface. At 1000° C. and after the same time only a very narrow layer was still free from carbon. At 1100° C. and with only half an hour heating the carbon had proceeded half-way towards the surface, while some cementite was still left in the core.

Experiments.

Testing Arrangement.—In a systematic investigation of the conditions which influence the surface decarburisation of steel,

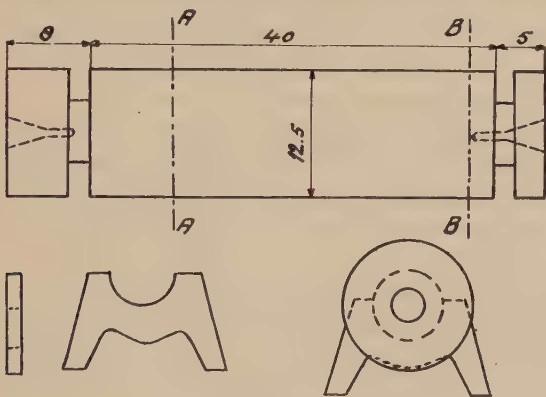

FIG. 11.

it is in the first place necessary to determine accurately not only the real depth of the decarburisation but also its intensity at different distances from the surface. For this purpose a microscopical investigation is not sufficient, and chemical analysis must be resorted to as well. In order to determine the carbon content of various layers under the surface the following method was used.

The specimens, the appearance of which may be seen from the upper part of Fig. 11, consisted of small cylinders with a diameter of about 12·5 millimetres, which were turned off in a small lathe. After the test they were again put into the lathe, and layers of 0·1 to 0·5 millimetre thickness were filed off between the sections *AA* and *BB*. The thickness of the layers was so chosen as to yield about 1 gramme of filings from each layer,

which is sufficient for an exact analysis by the combustion method. Any oxide scale which had formed on the surface was removed by means of emery-paper before filing. The diameter of the test cylinder was carefully measured by means of a micrometer screw-gauge. The remaining piece of the cylinder to the left of the section *AA* was afterwards used for microscopic investigation.

The testing arrangements, including apparatus for the preparation of the necessary gas mixtures as well as for heating the sample, were the same as illustrated before in Fig. 2. In order to permit of a free gas supply around the cylinder in the silica tube (8), it was supported on two pairs of iron feet as shown in the lower part of Fig. 11, so as to be held in the middle of the silica tube. The microscopic investigations have also proved that the decarburisation was equal all round.

The weight of the test cylinders, about 47 to 48 grammes, was carefully determined before and after heating, the decrease in weight affording an approximate measure of the intensity of the decarburisation in such cases where no oxidation of the surface had taken place.

Experimental results.—The experiments have so far only comprised the heating of test-pieces in a stream of dry carbon dioxide and carbon monoxide as well as dry air. Just as before, the gas mixture consisted of 60 per cent. nitrogen, together with carbon dioxide and carbon monoxide in varying percentages, their quantities together, however, always amounting to 40 per cent. The velocity of the gas was kept at 2 to 5 litres per hour, and more at higher temperatures, when the reactions took place so quickly that it could be said that the back part of the test cylinder was surrounded by a gas poorer in carbon dioxide than its front part.

The heating was performed at temperatures of 650°, 710°, 750°, 800°, 900°, and 1100° C.; the experimental material consisted of two steels, one hypo-eutectoid and one hyper-eutectoid, of the following composition:

Steel.	Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
5	0·81	0·27	0·06	...	0·010
17	1·11	0·43	0·13	0·030	0·017

Both steels were annealed before the tests, and were turned down to 12·5 millimetres diameter in order to remove the surface decarburisation, which was checked by means of filing and analyses as mentioned above. The carbon content was thereby found to be constant all over the section.

At 1100° C. the heatings were performed during a constant period of three hours in gas mixtures of varying carbon dioxide percentages and also in air. The results are given in Table XIII. and in Figs. 12 to 17. The degree of decarburisation given in

TABLE XIII.

Time, 3 hours; Temperature, 1100° *C.*

Carbon Dioxide. Per Cent.	Steel.	Decarburisation. %-mm.	Condition of the Surface.	Fig. No.
5	5	0·55	Not oxidised	12
,,	17	0·55	,, ,,	,,
10	5	0·76	,, ,,	13
,,	17	0·78	,, ,,	,,
15	5	0·75	Thin dark oxide layer	14
,,	17	1·05	,, ,,	,,
,,	17	1·05	,, ,,	,,
25	5	0·73	0·05 millimetre dark oxide layer	15
,,	17	1·10	0·02 ,, ,, ,,	,,
40	5	0·70	0·04 ,, ,, ,,	16
,,	17	1·14	0·03 ,, ,, ,,	,,
Air	5	0·72	0·25 ,, ,, ,,	17

the table will be explained later. Two tests were made on steel No. 17, with 15 per cent. CO_2, which, as seen in Fig. 14, are in good agreement. The course of the lower part of the curve of steel No. 5 in Fig. 16 seems to be erratic, a fact which may be due to an error of some kind.

The tests at 900° C. (Table XIV., Figs. 18–25) were carried out with three as well as with six hours' heating, otherwise the same conditions prevailed as previously.

At 800° C. some heatings were performed for six hours in a gas mixture which, according to Figs. 3 and 4, should have no decarburising influence, *i.e.* it contained somewhat more than 2 per cent. of CO_2. The specimen also showed that neither

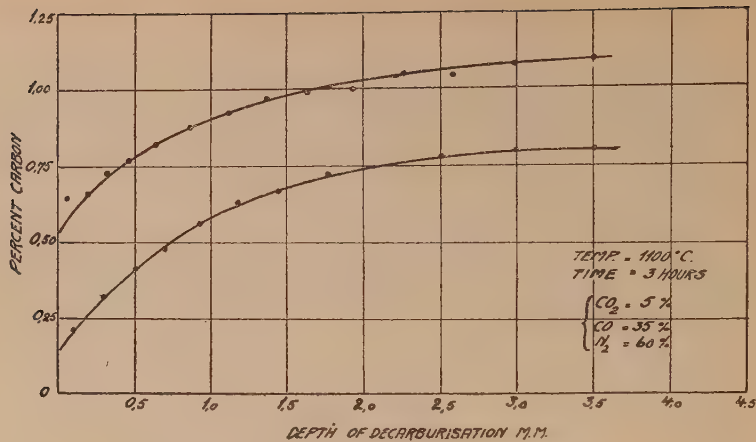

Fig. 12.

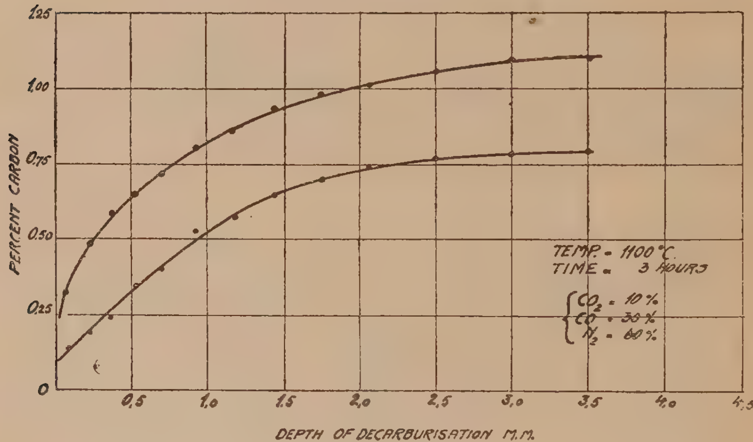

Fig. 13.

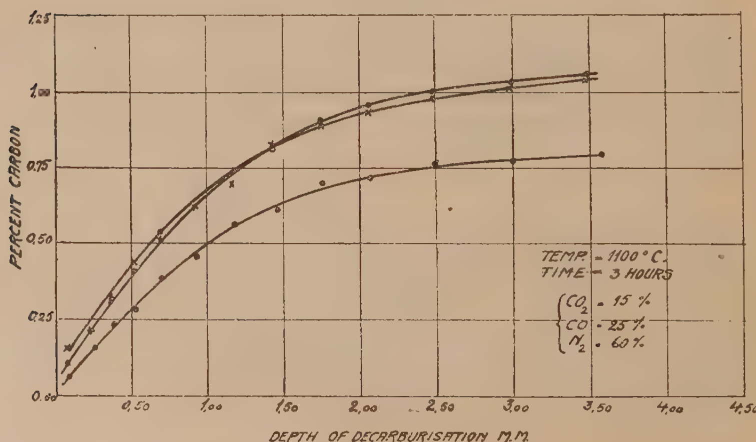

Fig. 14.

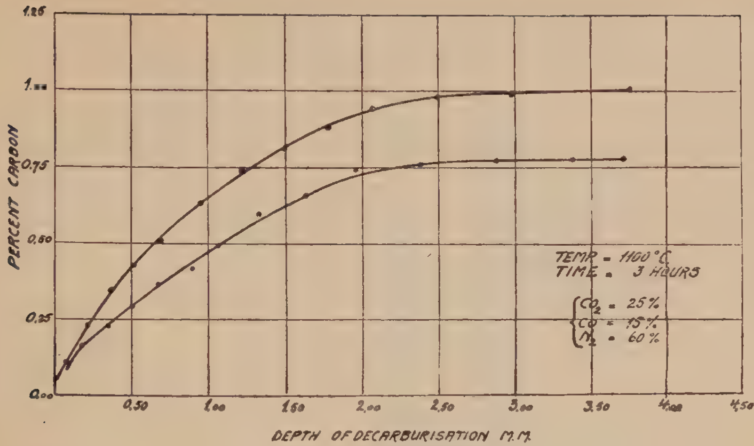

Fig. 15.

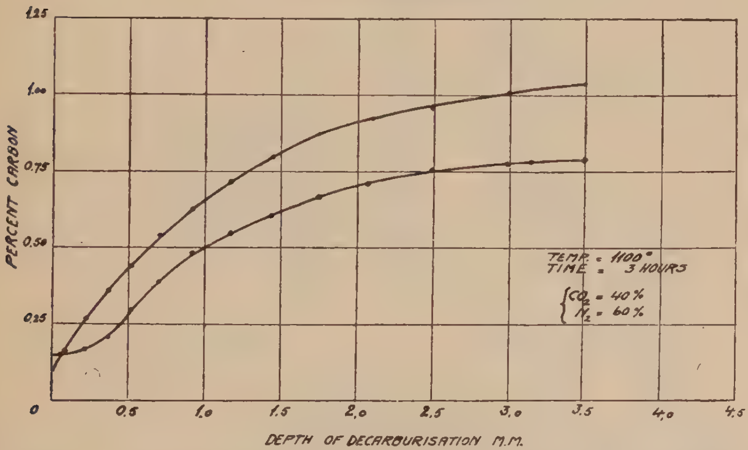

Fig. 16.

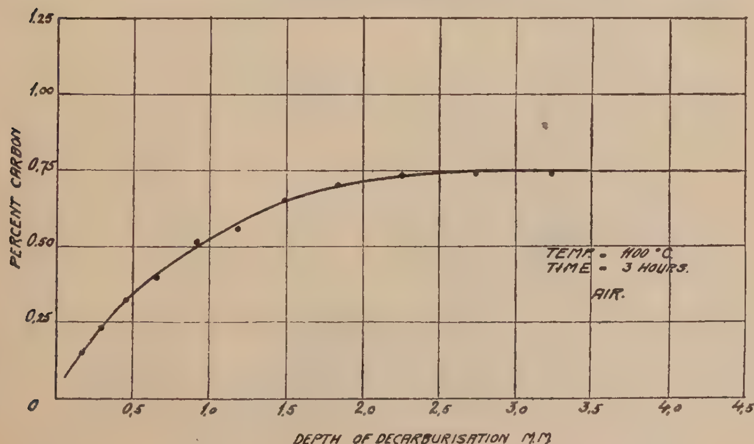

Fig. 17.

Table XIV.

Temperature, 900° C.

Carbon Dioxide. Per Cent.	Time. Hours.	Steel.	Decrease of Weight. Per Cent.	Decarburisation. %-mm.	Condition of the Surface.	Fig. No.
2	3	5	0·013	0·018	Not oxidised	18
,,	,,	17	0·014	0·019	,, ,,	,,
,,	6	5	0·020	0·024	,, ,,	,,
,,	,,	17	0·022	0·056	,, ,,	,,
5	3	5	0·025	0·045	,, ,,	19
,,	,,	17	0·022	0·034	,, ,,	,,
,,	6	5	0·062	0·13	,, ,,	,,
,,	,,	17	0·040	0·07	,, ,,	,,
10	3	5	0·074 *	0·18	,, ,,	20
,,	,,	17	0·052 †	0·12	,, ,,	,,
,,	6	5	0·109	0·25	,, ,,	,,
,,	,,	17	0·107	0·25	,, ,,	,,
15	3	5	0·084	0·20	,, ,,	21
,,	,,	17	0·072	0·18	,, ,,	,,
,,	6	5	0·129	0·32	,, ,,	,,
,,	,,	17	0·110	0·25	,, ,,	,,
25	6	5	...	0·33	Slightly oxidised	22
,,	,,	17	0·182	0·45	Not oxidised	,,
32·5	6	5	...	0·33	Very thin dark oxide layer	23
,,	,,	17	...	0·48	Slightly oxidised	,,
40	6	5	...	0·35	0·01 millimetre dark oxide layer	24
,,	,,	17	...	0·47	Slightly oxidised	,,
Air	6	5	...	0·22	0·05 millimetre red oxide layer	25

* Duplicate test, 0·072. † Duplicate test, 0·054.

Table XV.

Time, 6 hours; Temperature, 800° C.

Carbon Dioxide. Per Cent.	Steel.	Decrease of Weight. Per Cent.	Decarburisation. %-mm.	Condition of the Surface.	Fig. No.
2·1	5	0·001	0	Not oxidised	...
2·3	,,	0·002	0	,, ,,	...
2·2	17	0·002	0	,, ,,	...
5	5	0·010	0·011	,, ,,	26
,,	17	0·008	0·017	,, ,,	,,
10	5	0·028	0·052	,, ,,	27
,,	17	0·015	0·031	,, ,,	,,
15	5	0·030	0·055	,, ,,	28
,,	17	0·020	0·033	,, ,,	,,
25	5	0·083	0·180	,, ,,	29
,,	17	0·052	0·127	,, ,,	,,
32·5	5	...	0·175	Slightly oxidised	30
,,	17	...	0·100	,, ,,	,,
40	5	...	0·100	0·03 millimetre dark oxide layer	31
,,	17	...	0·057	Slightly oxidised	,,
Air	5	...	0·155	0·02 millimetre red oxide layer	32
,,	17	...	0·067	0·01 ,, ,, ,,	,,

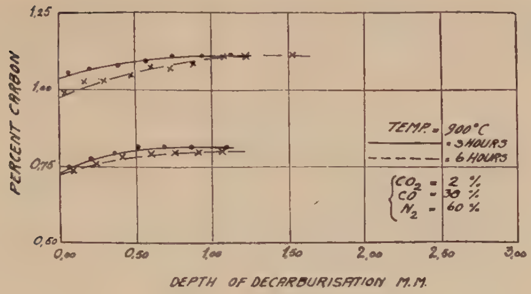

FIG. 18.

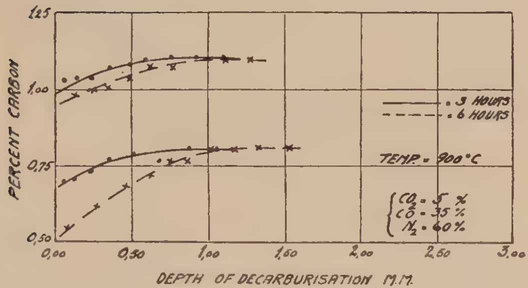

FIG. 19.

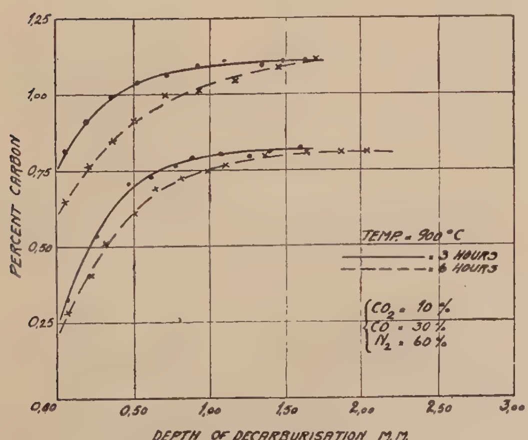

FIG. 20.

decarburisation nor carburisation had taken place. The other tests in various gas mixtures and in air were also carried out with

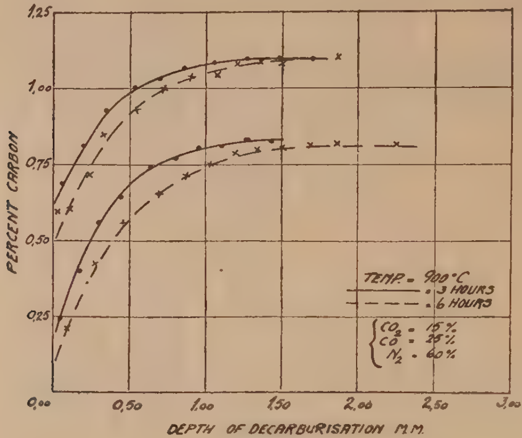

FIG. 21.

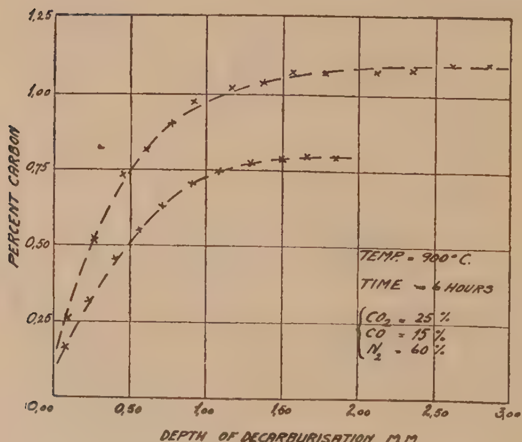

FIG. 22.

six hours' heating. The results are recorded in Table XV. and in Figs. 26 to 32.

At 750° C. (Table XVI.), the heating was performed in a gas with 25 per cent. CO_2 as well as in air. In the former case,

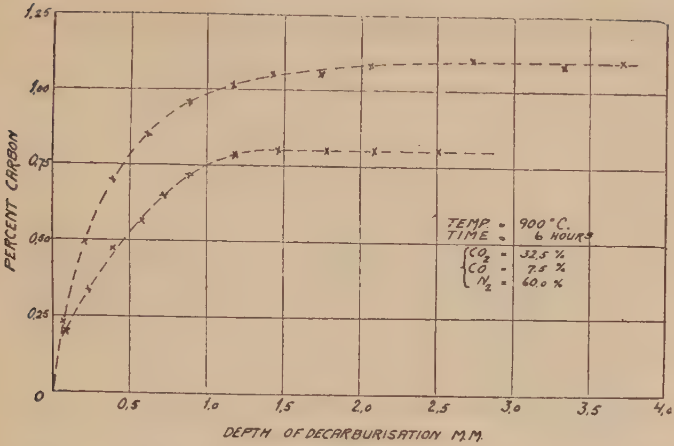

FIG. 23.

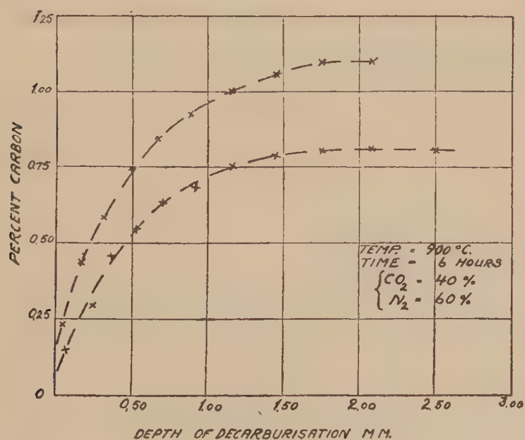

FIG. 24.

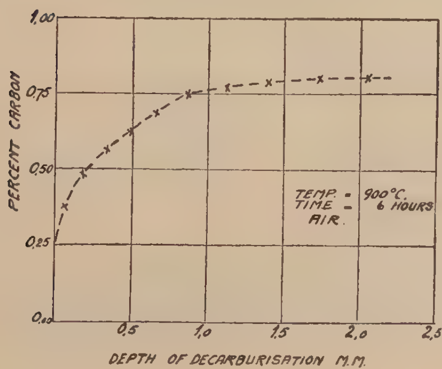

FIG. 25.

decarburisation was obtained as shown in Fig. 33, and in the latter

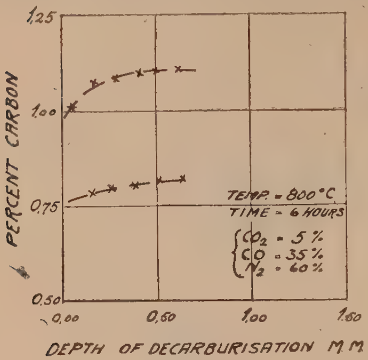

Fig. 26.

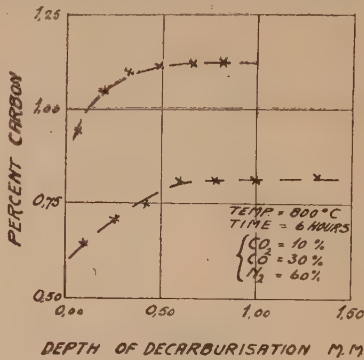

Fig. 27.

case no decarburisation could be traced, the specimens showing the original carbon content up to the very surface.

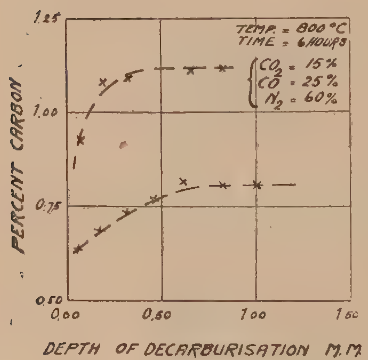

Fig. 28.

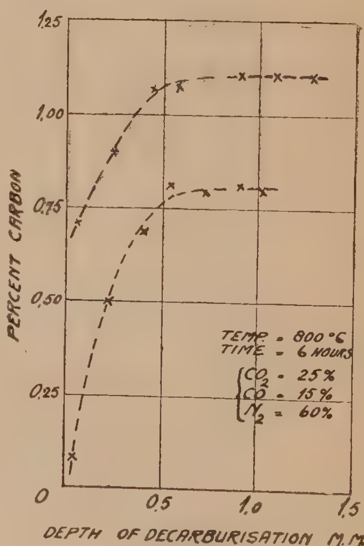

Fig. 29.

About the same results were obtained at 710° C. No decarburisation took place in air, but occurred when using gas mixtures of 15, 25, and 40 per cent. CO_2 respectively (Table XVI.,

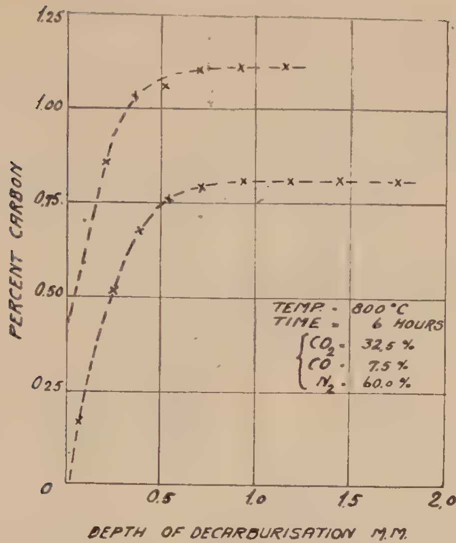

FIG. 30.

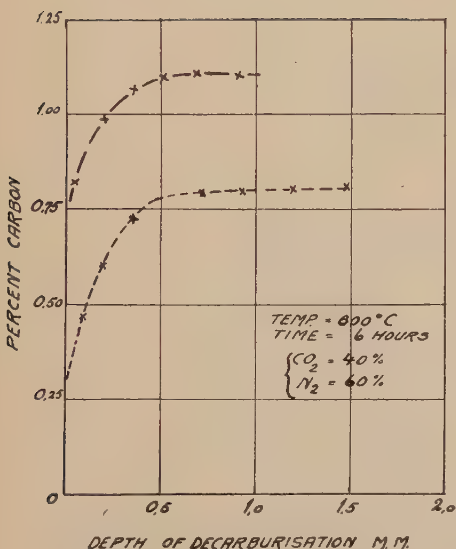

FIG. 31.

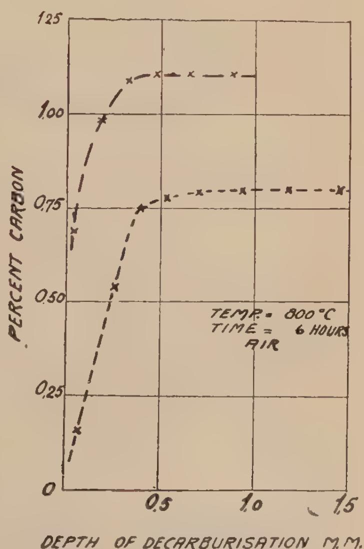

FIG. 32.

TABLE XVI.

Temperature. °C.	Carbon Dioxide. Per Cent.	Time. Hours.	Steel.	Decrease of Weight. Per Cent.	Decarburisation. %-mm.	Condition of the Surface.	Fig. No.
750	25	6	5	0·044	0·063	Not oxidised	33
,,	Air	,,	,,	...	0	0·02 millimetre red oxide layer	...
710	15	6	5	0·013	0·024	Not oxidised	34
,,	,,	,,	17	0·010	0·017	,, ,,	,,
,,	25	,,	5	0·019	0·046	,, ,,	35
,,	40	,,	,,	...	0·026	0·01 millimetre red oxide layer	36
,,	Air	,,	,,	...	0	0·02 ,, ,, ,,	...
650	20	10	5	...	0	Slightly oxidised	...
,,	Air	,,	,,	...	0	0·03 millimetre red oxide layer	...
,,	,,	,,	,,	...	0	0·03 ,, ,, ,,	...
,,	,,	6	,,	...	0	0·02 ,, ,, ,,	...

and Figs. 34 to 36). The greatest decarburisation was obtained with a CO_2 content of 25 per cent.

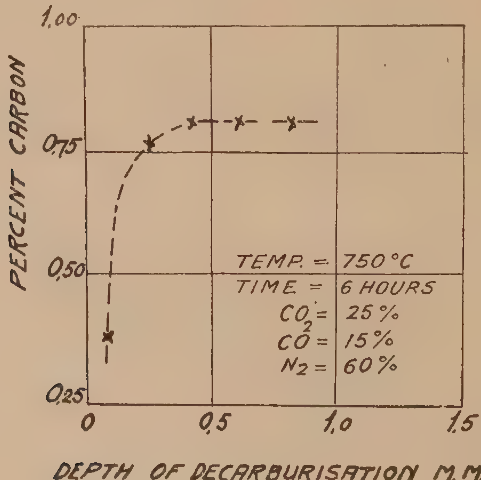

FIG. 33.

Finally, heatings were also made at 650° C. in a gas containing 20 per cent. CO_2, as well as in air. In neither case could

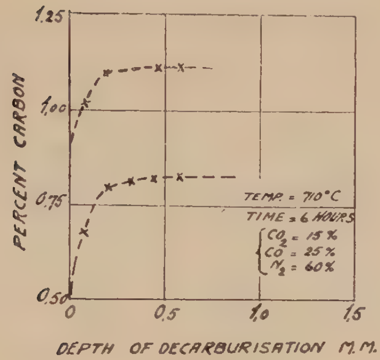

FIG. 34.

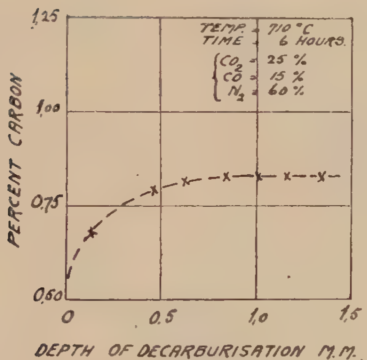

FIG. 35.

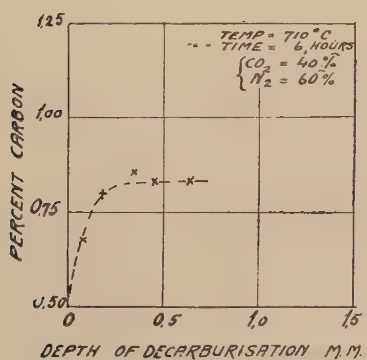

FIG. 36.

any decarburisation be traced, the analyses showing instead a slight increase of the carbon content in the outer layers.

Discussion of the Results.

The curves in Figs. 12 to 36 show the influence of the heating temperature and the composition of the gases on the depth of decarburisation as well as on the character of the decarburised zone. In order to illustrate how these factors influence the actual degree of the decarburisation, *i.e.* the oxidised amount of carbon, the following calculation was applied.

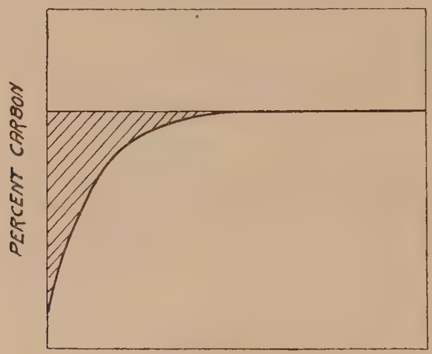

Fig. 37.

Fig. 37 gives a diagrammatic view of the above-mentioned decarburisation curves, with the decarburisation depths as abscissæ, and the carbon contents in the different layers as ordinates. The hatched area shows the amount of carbon removed on decarburising a piece of steel with a plane surface, and in the following calculation this amount will be designated the *degree of decarburisation*. Its dimensions are "%-mm." The same method of calculation has been applied in the case of the test cylinders, although it is not exactly valid for a cylindrical surface. The errors, however, are very inconsiderable for small decarburisation depths; besides, the main point is to obtain comparable results. Consequently, if the corresponding areas in Figs. 12 to 36 are measured as a means of determining the degree of decarburisation in the different tests, the values as recorded

in Tables XIII. to XVI. are obtained. The areas are always measured as if they were bounded at the top by the horizontal line, corresponding with the original carbon content. This is valid also for the curves at 1100° C., which do not reach the original carbon content. These areas have, however, only been measured up to a decarburisation depth of 3·5 millimetres.

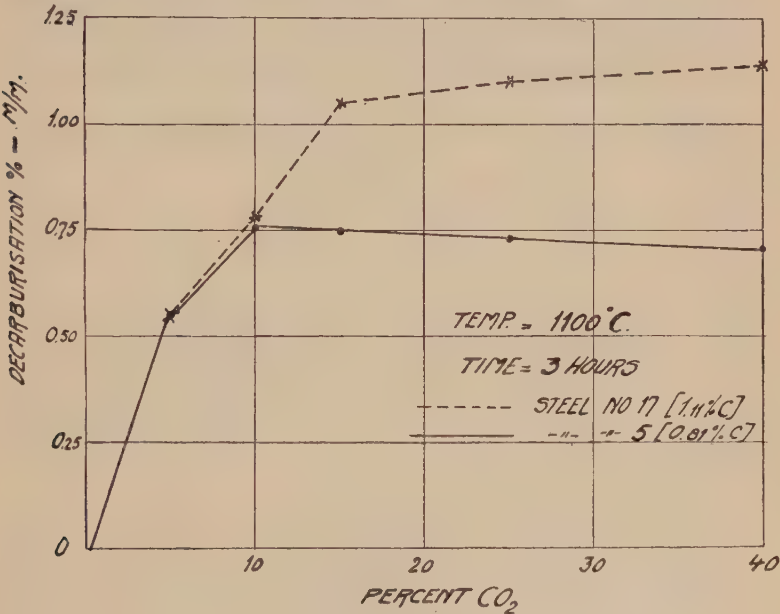

FIG. 38.

In Fig. 38 the degree of decarburisation is given as a function of the gas composition (CO_2 content) at 1100° C. It rises at first very rapidly with an increasing content of carbon dioxide, reaching its highest value at 10 per cent. CO_2 for the hypo-eutectoid steels and at 15 per cent. CO_2 for the hyper-eutectoid steels. It then seems to remain about constant at higher percentages of carbon dioxide, although the reaction speed ought to have increased. The maximum degree of decarburisation may possibly be determined by the diffusion speed of the carbon; it ought, however, to be observed that the formation of oxide scale on the surface of the specimen sets in at the breaks in the curves. It is

therefore also possible that the oxide scale in some way represses the decarburisation, presumably in such a way that it protects the underlying surface of the steel from the influence of the gases, rendering the gas diffusion more difficult.

At 900° C. (Fig. 39) the circumstances are analogous. The hypo-eutectoid steel reaches its maximum decarburisation at 15 per cent. CO_2, the hyper-eutectoid not until at about 25 per cent. CO_2. As seen from Table XIV., the formation of oxide scale sets in at about the same percentages of carbon dioxide.

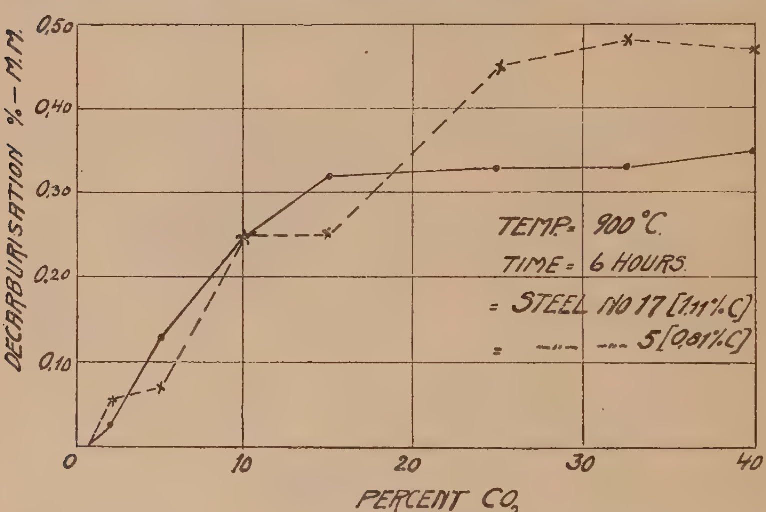

FIG. 39.

The curve for the hyper-eutectoid steel at lower carbon dioxide contents follows a somewhat strange course, a fact which will not be further discussed here, many of the influencing factors as yet being insufficiently investigated.

At 800° C. (Fig. 40) the formation of the oxide scale has so great an influence on the degree of decarburisation that the latter, after having reached its maximum at about 25 per cent. CO_2, decreases considerably at higher contents. The hypo-eutectoid steel here decarburises more than the hyper-eutectoid, while the contrary is the case at 900° C. and 1100° C. A somewhat stronger decarburisation is obtained in air than in gases containing 40 per cent. CO_2.

The facts brought out by the tests at 750°, 710°, and 650° C. are of great practical importance, showing that no decarburisation takes place on heating in air at these temperatures. Practical use has also been made of this circumstance, but the explanation generally suggested—namely, that the formation of oxide scale should proceed *pari passu* with the decarburisation, no surface

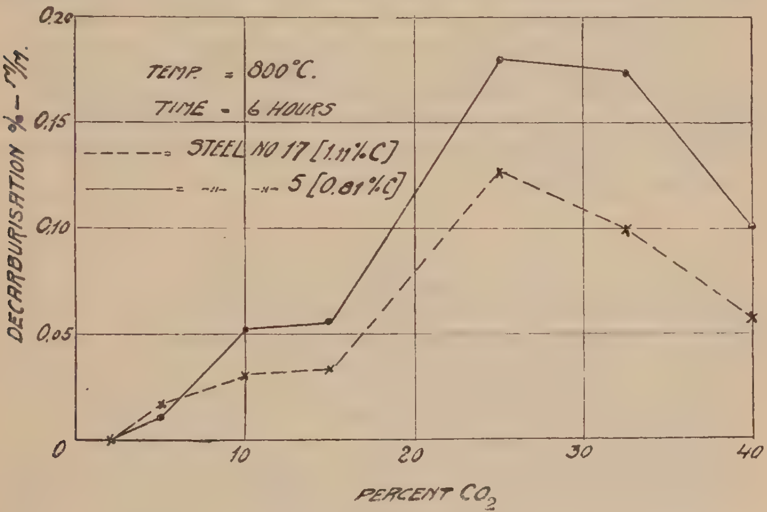

Fig. 40.

decarburisation thus taking place—seems to be wrong. The oxide layer is much too thin to be able to act in this way. Instead, just as at higher temperatures, it appears simply to form a protecting layer against the influence of the gases.

No detailed discussion on the course of the surface decarburisation and the possible means of suppressing it will be given here, as the investigations are not yet quite completed.

General Summary.

1. The equilibria of the reaction $3Fe + 2CO \rightleftarrows Fe_3C + CO_2$ have been determined between 700° and 1100° C. At 700° the equilibria coincide with those of Schenck,(1) but Schenck's theories on the equilibria above 700° C. have not been confirmed. The theoretical bearing of the equilibria found has been briefly mentioned.

2. The equilibria of the reaction $Fe_3C + 2H_2 \rightleftarrows 3Fe + CH_4$ have been diagrammatically presented; likewise a series of experiments have been carried out on the decarburising action of pure dry hydrogen.

3. In pure nitrogen at 1050° C. no decarburisation has been found other than that presumably depending on the influence of gases as well as oxides in the steel. No formation of cyanogen has been established.

4. A series of experiments has been carried out on the surface decarburisation of steel between 650° and 1100° C., on heating in different gas mixtures, consisting of carbon dioxide and carbon monoxide, as well as in pure air. The results obtained have been briefly discussed.

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DISCUSSION.

Professor C. Benedicks (Hon. Vice-President) said he desired to call attention to one fact which had not been sufficiently stressed in the paper. Most of the earlier metallurgists had restrained themselves from approaching equilibrium questions in spite of their great importance, the reason being that the diagrams published by earlier workers had been of such a complicated character that it was difficult, if not impossible, to understand them. He thought it might be said that the paper marked a new departure on that point. The method employed was admirably simple, and the results were presented in a very lucid way. He looked upon the paper as being an important contribution to the subject.

Dr. Andrew McCance (Uddingston, N.B.) wished to congratulate the authors very heartily. The experimental difficulties had been very great, and the interpretation of the results was no less difficult. He desired to discuss only one point, in connection with the upward tendency of the curve relating to the decarburisation at 710° C. That curve, theoretically, should be a horizontal line, but as the carbon contents of the steels were lowered, the curve tended upwards. He thought there was an alternative reaction which might occur there, namely, recarburisation direct, not from solid oxide on the surface of the specimen, but from dissolved oxide in the steel. That would explain the upward direction of the curve, but the authors had not taken that reaction into account.

To examine more exactly that possibility, in addition to the reaction considered by the authors

$$3Fe + 2CO = Fe_3C + CO_2 \quad . \quad . \quad . \quad . \quad (42)$$

the formation of carbide could also take place according to the following equation:

$$3FeO + 5CO = Fe_3C + 4CO_2 \quad . \quad . \quad . \quad . \quad (43)$$

The equilibrium of that reaction could be determined from that of equation (42) through the intermediate reaction:

$$FeO + CO = Fe + CO_2 \quad . \quad . \quad . \quad . \quad (1)$$

For instance, at 710° C., while the equilibrium proportion for equation (42) as determined by the authors was 8·2 per cent. CO_2, it could be deduced that the proportion of CO_2 in equilibrium with equation (43) was 38·0 per cent. It was possible, therefore, that the presence of small quantities of oxide would affect the equilibrium conditions and tend to increase the proportion of CO_2. As the carbon in the steels

of the authors' experiments became lower, any oxide present in the ferrite assumed a greater importance in so far as its effects on the equilibrium conditions were concerned. The increase in the equilibrium content of CO_2 at 710° C. in the authors' experiments might conceivably be due to that, and it would then be unnecessary to assume the solubility of carbon in α-iron to explain it. The solubility of ferrous oxide in steel was generally conceded, but the solubility of carbon in α-iron above about 0·03 per cent. would require strong positive proofs before it could be admitted.

After thoroughly studying the paper and also that of Schenck on the same reaction, he had to admit that there was still some uncertainty regarding the correct course of the reaction. The results recorded in the paper agreed fairly well with those obtained by Matsubara when plotted on a $\frac{1}{T}$ – log. K scale, and the extension of the line through Schenck's points fell more or less evenly through both sets of results. But the equations (42), (43) and (1) should possess a triple point, yet when plotted in that way that condition was far from realised, the three lines intersecting at widely different points. It would almost appear that while the equilibria determined experimentally were accurate and well defined, they were not represented by the equations generally considered as explaining them. The authors might not wish to agree to such a view, but he (Dr. McCance) felt strongly inclined to lend it support.

CORRESPONDENCE.

Mr. M. L. Becker (Manchester) wrote that the authors were to be congratulated upon having established an equilibrium diagram for gaseous mixtures of CO and CO_2 in contact with austenite of varying carbon content and at varying temperatures. As pointed out in the paper, that investigation was a necessary preliminary to further work on the susceptibility of iron and steel to carburisation or decarburisation by furnace gases. Although Schenck and other workers had done much in that field the authors' results marked a very distinct advance. He (Mr. Becker) had for some time been investigating the same equilibria as part of a research for the British Cast Iron Research Association. Although as yet incomplete, the results seemed mostly to agree well with those of the authors—a fact which was the more satisfactory as the experimental method adopted was quite different.

The authors had been obliged to work with gases containing 60 per cent. of nitrogen, but that was, perhaps, rather a pity because the accuracy of the ratio $\frac{[CO]^2}{[CO_2]} = K_1$ was not so great as it would have been if no nitrogen had been present. It was therefore surprising

that such very definite deductions had been made with regard to the relative carbon pressures of cementite plus saturated austenite and elementary carbon. A reference to Table II. of the paper would show that at 1100° C. no values for cementite plus saturated austenite had been obtained, the steel with the highest carbon content (No. 23) consisting of unsaturated austenite at that temperature. The same probably applied at 1000° C. The statement that the carbon pressure of cementite was less than that of elementary carbon above 800° C. would therefore appear to be based on the evidence contained in Table IV. There, the same steel, containing 1·58 per cent. carbon, was carburised in three hours at 900° C. to 1·64 per cent. carbon by a gas containing 0·55 per cent. CO_2. The value, according to Boudouard, for CO_2 in equilibrium with carbon was 2·9 per cent. at a pressure of one atmosphere. That was equivalent to approximately 0·48 per cent. CO_2 when, as in the above carburising experiment, the sum of the partial pressures of CO and CO_2 were together equal to 0·4 atmosphere. It was true that Rhead and Wheeler had found a lower percentage of CO_2 in equilibrium with carbon at that temperature, but that merely proved that the values so far published could only be taken as correct within appreciable limits. Whilst not wishing to criticise the authors' technique, which was obviously of the highest order, he would suggest that the difference between 0·55 and 0·48 per cent. was within the combined experimental error of their own and Boudouard's work. Perhaps the authors would mention what method was used for checking the composition of the gas mixtures.

Another point which should be borne in mind was that the steel in question (No. 23) contained a notable amount of manganese, an element which, in view of measurements quoted by Schenck, seemed to exercise a lowering effect on the carbon pressure of cementite.

Quite apart from the evidence appearing in the paper, it was an established fact that cementite tended to break down into graphite and austenite at temperatures above 800° C. The presence of CO and CO_2 in no way interfered with that reaction and according to most authorities facilitated it, so that it must be assumed that the carbon pressure of the cementite was greater than that of the graphite. In addition to that he (Mr. Becker) had shown, in a recent paper to the Iron and Steel Institute, that iron, carburised to equilibrium in graphite in the presence of CO and CO_2, did not reach the saturation point with regard to cementite—a fact which again seemed to support the view that the carbon pressure of graphite was inferior to that of cementite and saturated austenite. He had attempted to measure the carbon pressures in question over a range of temperature 700° to 950° C., and had found them apparently exactly the same. The similarity was, however, apparent rather than real and could be attributed to the cementite having become coated with carbon at the outset of each experiment. On the other hand, allowing for experimental error, the results showed that the carbon pressure of carbon was certainly not

greater than that of cementite to anything approaching the extent indicated by the authors at 900° C.

The authors had calculated the equilibrium concentrations of CO and CO_2 for a total pressure of one atmosphere, but it would be very interesting to know whether they had carried out any experiments at that pressure, and if so, whether they had noticed evidence of the equilibrium curves being deflected in the vicinity of that indicating oxidation of pure iron. The presence of FeO in solution would almost certainly affect the value of K_1, and it therefore seemed somewhat risky to rely on the invariability of the constant at higher pressures, where conditions approached those involving actual oxidation.

The Authors wrote that they had not discussed whether the possible presence of FeO in solution might influence the equilibrium, since practically no experimental data on that point existed. On purely theoretical grounds, however, they could not accept Dr. McCance's point of view. He seemed to consider that reaction (43) was a bivariant equilibrium, which in the t—x diagram might be represented by a line situated somewhere between the cementite-austenite line and the line $FeO + CO \rightleftarrows Fe + CO_2$ in Fig. 5 (as was also suggested by Matsubara). Throughout the temperature range, where the cementite as well as the ferrous oxide were dissolved in the iron (a surplus of any of those substances being excluded), the system contained in fact only one solid phase, *i.e.* a solid solution of ferrous oxide and cementite in iron, and was, consequently, trivariant and not bivariant. Thus the system corresponding to reaction (43) had the same character as the system (42) investigated by them (the authors). A certain carbon concentration and a certain FeO concentration in the solid solution might correspond to any relative proportion of carbon monoxide and carbon dioxide. They failed to understand how Dr. McCance had been able to calculate any fixed equilibrium for reaction (43), but they did not consider it surprising that the theoretical calculation did not correspond with the experimental data. The extent of the influence of what was certainly only a very small quantity of dissolved FeO on the vapour pressure of the carbon present in solid solution was certainly difficult to decide, but they had reason to believe that that influence was very slight. At all events Dr. McCance's choice of an example of the influence of the ferrous oxide, namely, that it should cause a deviation for the isotherm at 710° C., did not seem to be a happy one. At that temperature the carbon should not be soluble in iron, and the equilibrium should therefore depend entirely on the carbon pressure of the free cementite, and it should be quite uninfluenced by whether the iron contained any oxide or not. However, as they had already pointed out, the authors would in no way draw any conclusions concerning the solubility of carbon in α-iron, but instead they hoped that the continuation of the investigations would give evidence on that point.

Dr. McCance gave some data regarding the CO_2 content for the equilibria (42) and (43) at 710° C., namely 8·2 and 38·0 per cent. respectively. Those values, however, did not seem to correspond with each other, as the first was valid for a partial pressure of $CO + CO_2 =$ 0·4 atmosphere, whereas the second had presumably been calculated by Dr. McCance for one atmosphere. At that pressure the former value should be 34·6 per cent. CO_2 (see Table IX.).

Finally, the authors were very interested in the communication of Mr. Becker, and were pleased to note that he had attained similar results in another way. They agreed with his view on the desirability of carrying out experiments at a pressure of one atmosphere in connection with the position of the cementite-austenite line at higher temperatures. Some of the determinations of the carbon pressure, &c., were as yet doubtful. The results so far obtained in that direction must, however, be considered as evidence that the carbon pressure of cementite at 900° as well as 1000° C. was less than that of elementary carbon, but that question should be subjected to a repeated investigation (at one atmosphere). In addition, steels with higher and lower percentages of manganese could then be used in order to study the influence of manganese on the equilibrium. However, at 800° C. a moderate manganese content had shown no pronounced influence. On account of the great extent of the investigation there had as yet been no time to make any tests at one atmosphere.

A PHYSICAL INVESTIGATION INTO THE CAUSE OF TEMPER-BRITTLENESS.*

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and

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Introduction.

The cause of temper-brittleness is as obscure to-day as it was when the phenomenon itself was first observed. The effect of variation of heat treatment on the notched-bar impact value of steels susceptible to temper-brittleness is now well known, mainly as the result of the exhaustive researches of Greaves and Jones.[1, 2] The effect of variation in composition is also fairly well known as the result of work by the same investigators,[3] by Andrew and Green,[4] and by Griffiths.[5] But no satisfactory explanation of the variations in impact value has yet been advanced.

It is generally accepted that whereas the impact value falls when a steel which is susceptible to temper-brittleness is cooled slowly from the tempering temperature, yet no appreciable change has been shown to take place in any other mechanical property (with the possible exception of a small change in elastic limit), in any physical property (with the possible exception of some magnetic properties), or in the microstructure.

In consequence of the apparent absence of any physical changes in any way commensurate with the great change indicated by the arbitrary notched-bar impact tests, the value of all or any of the modifications of the latter test as a measure of the real toughness or brittleness of a material has naturally been questioned. From the work published up to the present it is easy to conclude that a minute and almost negligible change in the condition of a steel is magnified out of all proportion by a notched-bar impact test.

It is evident that the subject can never be placed on a satisfactory basis until the physical change which produces the

* Received July 1, 1926.

alteration in impact value is elucidated, and, in spite of the negative results published by other workers, the authors felt that an accurate physical investigation would reveal a physical change. They were encouraged in this belief by the absence, among published researches, of any systematic investigation of temper-brittleness on physical lines.

Physical Determinations by Other Investigators.

Greaves and Jones [(2)] (*loc. cit.*, pp. 208–213) have compared the specific gravity, hardness, and specific resistance of tough and brittle specimens in which tempering effects have been equalised. They found that the specific gravity of water-cooled tough steel was from 0·0004 to 0·0010 less than that of the brittle steel, but that when the tough steel was reheated to 200° C. this difference was greatly reduced. This rise in specific gravity on low-temperature annealing they attributed to removal of a condition of strain in the water-quenched steel, and they concluded that "the difference in density due solely to the condition of toughness or brittleness appears to be at the most 1 part in 20,000."

From Brinell hardness determinations on water-quenched and slowly cooled specimens they conclude: "These results show that when unequal tempering effects are eliminated in producing tough and brittle material, there is no appreciable difference in the hardness of the two varieties."

From determinations of specific resistance on similarly treated specimens they conclude that: "The resistivity at 0° C. of tough and brittle material was identical within the experimental error."

The same investigators found that in the majority of steels the elastic limit in the brittle condition was about 3 tons per square inch higher than that of the same steels in the quenched tough condition, but that when moderate rates of cooling were adopted, or when the quenched steel was subjected to low-temperature annealing, the elastic limits of the two conditions were equalised.

Rogers [(6)] claimed that the brittle state was softer than the tough, but no attempt was made in his experiments to differentiate between the effect of "extra-tempering" in the slowly cooled specimens and the effect of the change to the brittle condition.

The softening effect observed in many cases has always been

attributed to "extra-tempering," and Greaves and Jones, as already stated, produced very good evidence to show that when tempering effects were equalised there was no softening in the brittle state.

Thermal curves taken by the differential method have been published by Rogers [6] and by Greaves and Jones.[2] These point to the possibility of an absorption of heat on heating and an evolution on cooling through the "brittleness range."

More recently Guillet [7] has carried out work on dilatation and thermo-electric power. His conclusions are as follows: "Dilatation experiments did not furnish any information," and "Thermo-electric tests gave equally no indication."

The magnetic properties of tough and brittle steel appear to have been compared in only one case, by Kayser.[8] He gave figures showing that the remanence of one steel, which was susceptible to brittleness, increased 40 per cent. on slow cooling.

Figures given by Gebert [9] of magnetic tests on a nickel and on a nickel-chromium steel, quenched and tempered at various temperatures, followed by air-cooling, showed that the residual induction in both steels increased very considerably after tempering at 425° C. and above. Gebert did not, however, compare specimens in the tough and brittle condition.

Similar experiments by Dowdell [10] on a number of carbon and special steels showed a similar rise to that observed by Gebert, but only in a few steels was the rise at all pronounced, and the change was much greater in all his carbon steels (0·7 to 1·2 per cent. carbon) than in any of the special steels examined. He did not compare brittle and tough steels.

It is evident from the work of Dowdell that the rise in residual induction after tempering to 400° C. or 500° C. is very marked in steels which are not susceptible to temper-brittleness. Results published by other workers [11] support this view. It does not necessarily follow, however, that this magnetic change is unconnected with temper-brittleness.

It is clear that all the evidence published up to the present points to the absence of any substantial physical change accompanying the change from the tough to the brittle condition.

Experimental Method.

The main experimental procedure used in the first part of this investigation was the method of heat treatment of suitable specimens *in vacuo* followed by determinations of specific volume and Brinell hardness.

Specimens about 25 grammes in weight were heat-treated in a wire-wound electric furnace having a transparent fused silica tube. The vacuum was obtained by a Toepler mercury pump of large capacity. It has been found possible to heat-treat specimens at high temperatures for lengthy periods without any alteration in composition of the specimens.

The specimens were thoroughly ground all over and finished on 1G French paper for the determination of the specific volume. The Brinell marks were completely removed between each treatment, but it may be said that Brinell marks produced no appreciable difference in the specific volume in a number of determinations which were made on specimens before and after Brinelling.

The specific volume was determined by comparison with a standard specimen of known specific volume by weighing in paraffin. The method has been fully described by Andrew, Fisher, and Robertson.[12] The experimental error is certainly not more than $\pm 0{\cdot}00001$, and in many cases the present authors have obtained repeat determinations identical or almost identical in the sixth place of the specific volume.

First Series of Experiments.

Analysis of Steels.

Steel.	C. %	Mn. %	Si. %	P. %	S. %	Ni. %	Cr. %	Description.
A22	0·48	0·18	0·11	...	...	...	...	Plain carbon
NP1	0·31	0·75	0·112	0·013	0·029	3·64	...	Nickel, low phosphorus
NP5	0·33	0·70	0·065	0·098	...	3·66	...	Nickel, high phosphorus
AW22	0·33	0·52	0·177	0·016	0·014	3·48	0·76	Nickel-chromium
AW23	0·37	0·54	0·149	0·013	0·012	4·55	1·14	Nickel-chromium

NP1 and NP5 are two of the steels used by Andrew and Green [4] in their work on the effect of phosphorus on the notched-bar

impact value. NP1 has a very low susceptibility to temper-brittleness, whereas NP5 has a high susceptibility.

AW22 and AW23 were available in very small quantity only, and impact tests could not be carried out on these steels. They were both assumed to be susceptible in greater or lesser degree to temper-brittleness.

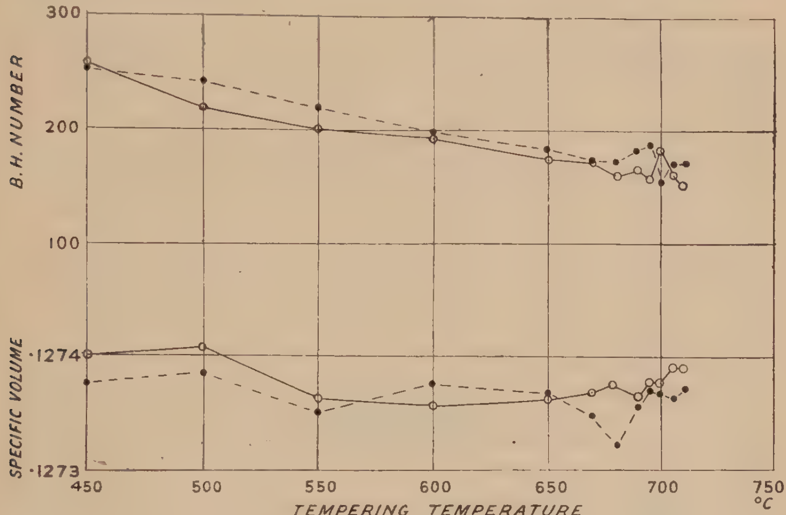

Fig. 1.—Carbon Steel, A22.
Full line.—Specimen quenched in water.
Dotted line.—Specimen slowly cooled at 2° C. per minute.

Two sets of specific volume specimens of the above five steels were treated as follows:

First Set.—Oil-quenched from 850° C. and tempered for three hours at various temperatures from 450° C. upwards and quenched in water.

Second Set.—The same treatment, except that tempering was followed by slow cooling at a rate of 2° C. per minute instead of water-quenching. This rate of cooling was adopted in order to have this preliminary series of experiments completed within a reasonable time. It was thought to be sufficiently slow to produce some change in the steels, although a much slower degree of cooling is necessary to produce the maximum degree of brittleness.

Quenching in oil from 850° C. preceded *each* tempering treatment.

The specific volume and Brinell hardness results after each treatment are plotted in Figs. 1, 2, 3, 4, and 5.

Steel AW23 (Fig. 5), which contains the most nickel and

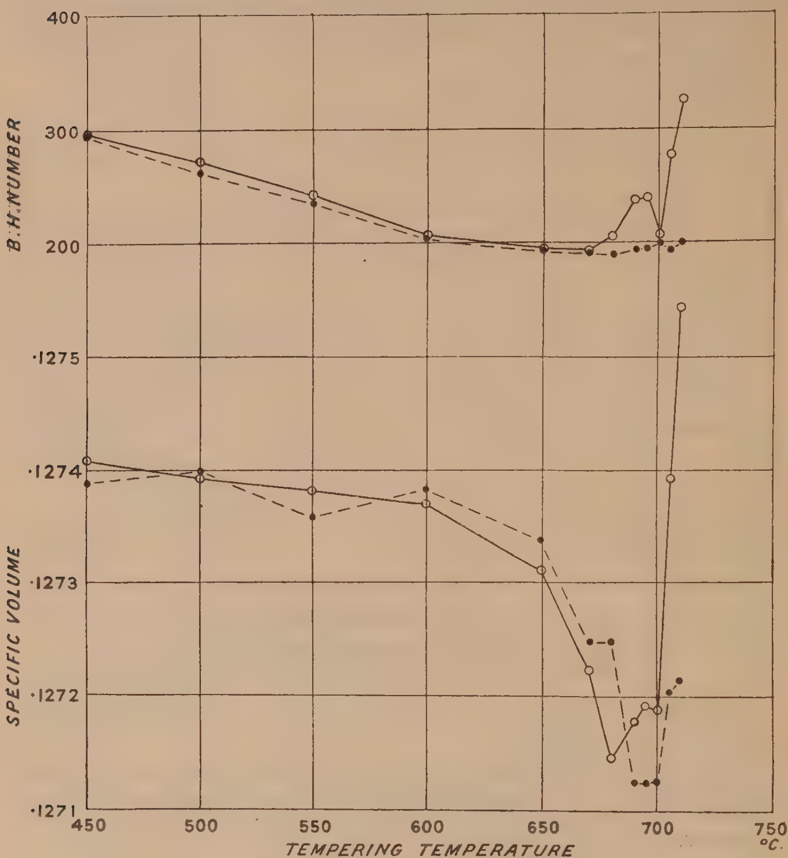

Fig. 2.—Nickel Steel (Low Phosphorus), NP1.

Full line.—Specimen quenched in water.
Dotted line.—Specimen slowly cooled at 2° C. per minute.

chromium, shows a very marked and consistent change from 550° C. upwards in both hardness and specific volume, but in the other steels no notable difference is apparent between the quenched and the slowly cooled specimens, except possibly in the other nickel-chromium steel, AW22 (Fig. 4), which shows indications

of a slight change in specific volume only, similar to the much larger change observed in Steel AW23. No change is evident between the quenched and slowly cooled specimens of Steel NP5,

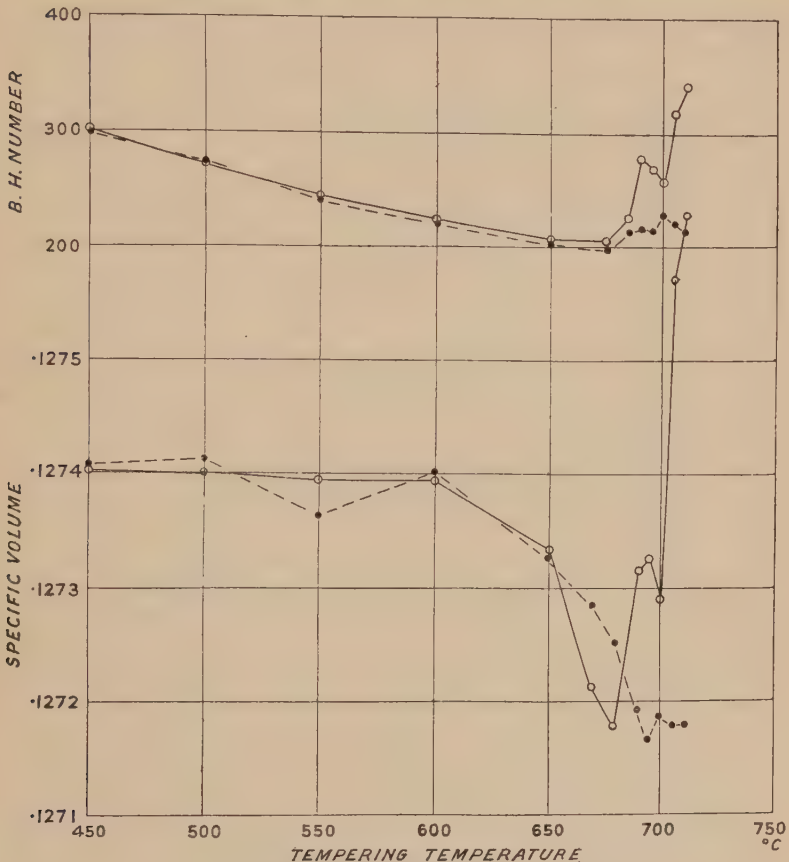

FIG. 3.—Nickel Steel (High Phosphorus), NP5.
Full line.—Specimen quenched in water.
Dotted line.—Specimen slowly cooled at 2° C. per minute.

which has been shown to be highly susceptible to temper-brittleness.

It is evident from the curves obtained for the carbon and nickel steels that quenching from the tempering temperature up to about 680° C. has no appreciable effect on the hardness or on

the specific volume. The possibility that a strain effect induced by quenching is alone responsible for the very marked changes in hardness and in specific volume in Steel AW23 is completely

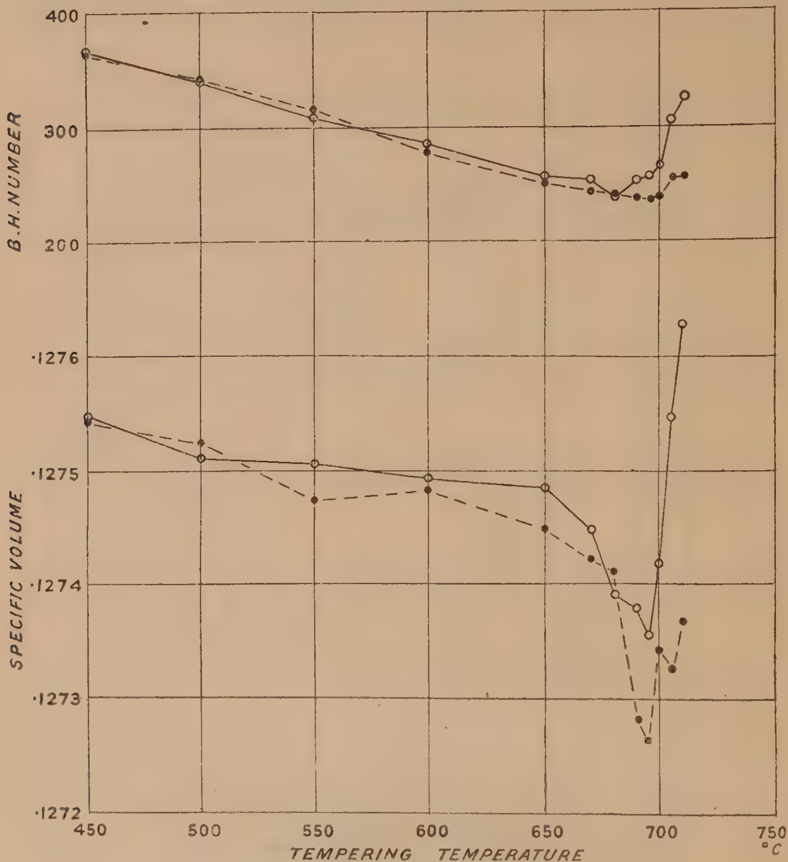

Fig. 4.—Nickel-Chromium Steel, AW22.

Full line.—Specimen quenched in water.
Dotted line.—Specimen slowly cooled at 2° C. per minute.

discountenanced by the entire absence of any such change in the carbon steel or in the nickel steels, as well as by the very magnitude of the change in Steel AW23 itself.

In order to find whether the extra heating received by the slowly cooled specimens had produced any relative difference

between them and the quenched specimens, the ten specimens were resubjected, at the end of the series of experiments, to the original tempering treatment of three hours at 450° C. All the

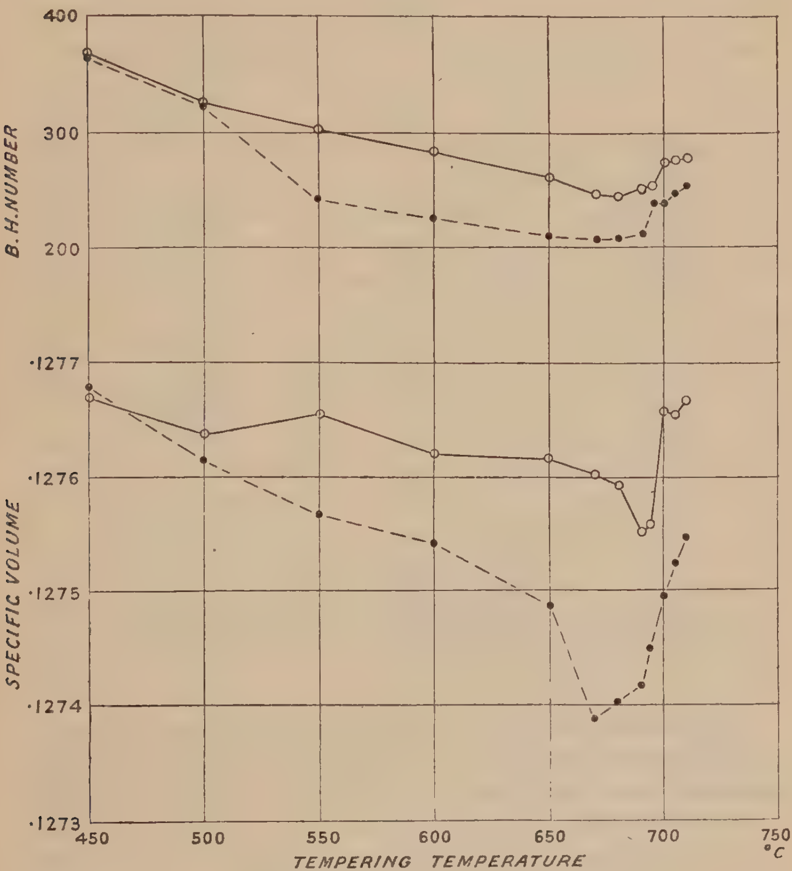

Fig. 5.—Nickel-Chromium Steel, AW23.

Full line.—Specimen quenched in water.
Dotted line.—Specimen slowly cooled at 2° C. per minute.

specimens were quenched from this tempering temperature. The figures for all the treatments at 450° C. are given in Table I. The two specimens of Steel AW23 were also resubjected to a six-hours treatment at 670° C., both specimens being quenched from

the tempering temperature. These results are also shown in Table I.

TABLE I.

Steel.	Original Treatment. Tempered Three Hours at 450° C.			Repeat at End of Experiments. Tempered Three Hours at 450° C.		
		Specific Volume.	Brinell Hardness.		Specific Volume.	Brinell Hardness.
A22	Quenched	0·127401	258	Quenched	0·127381	258
	Slowly cooled	0·127374	256	,,	0·127418	256
NP1	Quenched	0·127407	298	,,	0·127397	289
	Slowly cooled	0·127387	299	,,	0·127416	287
NP5	Quenched	0·127430	302	,,	0·127448	300
	Slowly cooled	0·127407	300	,,	0·127432	298
AW22	Quenched	0·127548	365	,,	0·127551	356
	Slowly cooled	0·127543	364	,,	0·127552	361
AW23	Quenched	0·127666	369	,,	0·127679	365
	Slowly cooled	0·127677	367	,,	0·127678	367

Steel.	Original Treatment. Tempered Three Hours at 670° C.			Repeat Treatment. Tempered Six Hours at 670° C.		
		Specific Volume.	Brinell Hardness.		Specific Volume.	Brinell Hardness.
AW23	Quenched	0·127602	248	Quenched	0·127580	240
	Slowly cooled	0·127388	209	,,	0·127615	240

These results clearly prove that no appreciable alteration in composition had taken place in any of the specimens, and incidentally show the excellence of the method of heat treatment in an efficient vacuum.

The extra three hours' tempering at 670° C. given to the specimens of Steel AW23 shows that the effect of extra-tempering on slow cooling must be very small. Three hours' extra-tempering *at the high temperature* has given only a drop of 8 Brinell and 0·000022 in the specific volume.

It is also shown in the Second Series of Experiments, described below, that extra-tempering could not be made to explain the marked difference obtained on slow cooling Steel AW23. The conclusion that this difference in specific volume and in hardness

is due to a radical physical change in the steel was thus well substantiated.

This contraction and softening of the steel on slow cooling is what one would expect from the separation of a solute which has been in solid solution at the tempering temperature and which is retained in the latter condition on quenching the steel in water. This will be more fully discussed after further experiments are described below.

The fall in specific volume in the nickel steels as the tempering temperature is raised is very considerable and increases rapidly at the higher temperatures. Benedicks [13] has given figures to show that troostite and pearlite have the same specific volume, but it does not follow that the state of division of the carbide in a steel has no effect on this property. Indeed, the authors have obtained a great deal of evidence which shows that the state of distribution and the state of division of the carbide has a very considerable influence. Globularisation in the nickel steels is exceedingly rapid as compared with carbon steels, and the effect of aggregation of the carbide particles into globules leads evidently to the closest packing arrangement of the mixture of carbide and iron. Any solubility of the carbide in α-iron would certainly increase with temperature, and would oppose the observed fall in specific volume, so that the latter seems to be due entirely to alteration of the state of aggregation of the carbide. The rapid change in rate of globularisation with slight variation in tempering temperature above 600° C. is probably responsible for the variable impact figures obtained in nickel steels which has been noted by Griffiths.[5] It will be seen from Figs. 2, 3, 4, and 5 that the effect of globularisation is so marked in the nickel and in the nickel-chromium steels that even where slight solution of carbide in γ-iron at 680° C. or 690° C. leads to an increase of hardness on quenching, the specific volume still falls.

This series of experiments was continued to higher temperatures. The results in the Ac1 critical range will not be specially commented on in this paper, but are included in the graphs as being part of a continuous series of experiments. It may be pointed out, however, that the results for Steel AW23 in the critical range show that, even when considerable solution in γ-iron is induced at the tempering temperature, slow cooling

through the "brittleness range" still gives a large fall in specific volume and in hardness, similar to that obtained at lower temperatures.

Second Series of Experiments.

It was thought advisable to find out the effect of extra-tempering on the specific volume and hardness of nickel-chromium steels.

The following steels were taken:

Analysis.

Steel.	C. %	Mn. %	Si. %	P. %	S. %	Ni. %	Cr. %	
AH	0·31	0·47	0·310	0·015	0·021	4·46	1·41	
NC	0·31	0·57	0·145	0·026	0·029	3·20	0·83	
NR3	0·36	0·34	0·275	0·016	0·021	1·90	1·15	
AW22	0·33	0·52	0·177	0·016	0·014	3·48	0·76	As in First Series
AW23	0·37	0·54	0·149	0·013	0·012	4·55	1·14	

(The three new nickel-chromium steels, AH, NC, and NR3, were obtained, through the kindness of Dr. McCance, of the Clyde Alloy Steel Co., Motherwell, in sufficient quantity to allow of impact testing to correlate with the physical determinations.)

Specimens of these steels were tempered (after oil-quenching from 850° C.) at 650° C. for two hours and quenched in water. They were then retempered at 650° C. for additional periods of six hours each and quenched in water after each treatment. The specific volume and the hardness were determined after each treatment, and the results are plotted in Fig. 6.

The fall in specific volume and in hardness is small in all the steels for short periods of extra-tempering. Six hours of extra-tempering at 650° C. produce only a difference of approximately 20 Brinell and 0·00004 in the specific volume. It is certain that the effect of extra-tempering is much greater at 650° C. (see Figs. 4 and 5) than at lower temperatures during slow cooling, and thus it is apparent that any marked contraction or softening which is observed in slowly cooled nickel-chromium steels cannot be attributed to extra-tempering. The curve for Steel AW23 shows conclusively that the change observed on slow cooling in

the First Series of Experiments is not due to the effect of extra-tempering, but must be due to a physical change which takes place during cooling.

This series of experiments was carried much further than

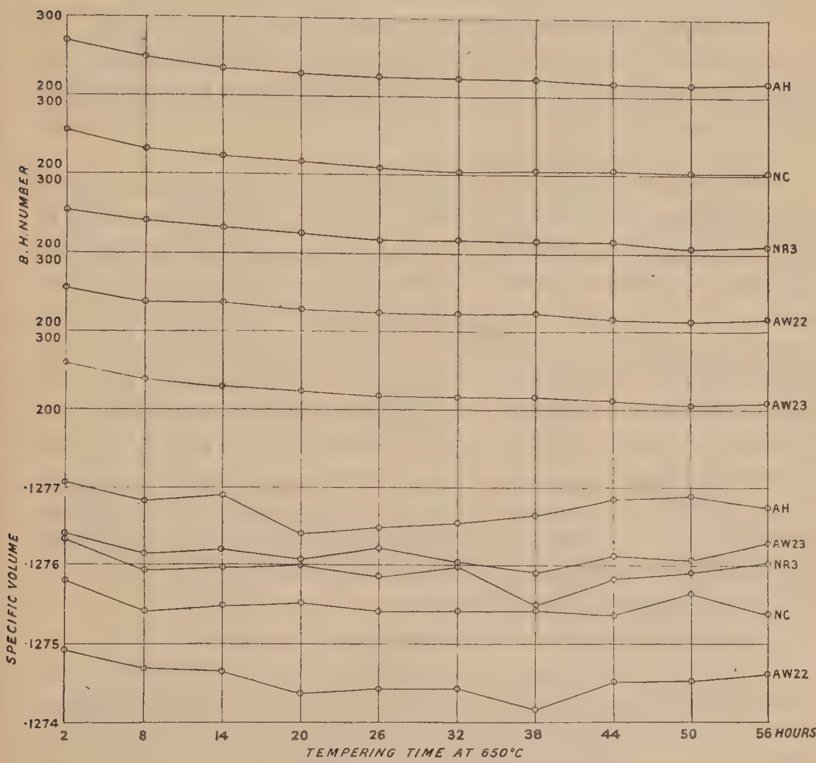

FIG. 6.—Five Nickel-Chromium Steels.

originally intended, owing to an apparent very slight rise in specific volume after the specimens had been tempered for a considerable period. After this rise was first noticed each succeeding tempering treatment merely seemed to accentuate it, except in Steel NC, which shows a rise in one treatment only. The hardness dropped slightly but continuously in all the steels until the last treatment, when it rose slightly in each case. The hardness results show that the rise in specific volume is not due to

graphitisation of the carbide, but the evidence is too meagre to justify a definite explanation at present.

Third Series of Experiments.

A number of experiments were carried out on Steels AH, NC, and NR3 to find their susceptibility to impact brittleness (as measured by the standard Izod test), and also to show the effect of tempering temperatures above the normal temperatures generally used in these tests.

Bars of the steels were first oil-quenched from 850° C. and then tempered for two hours at 650° C., 670° C., 680° C., and 690° C. The treatments were carried out in a large electric tube furnace having an effective heating length of about 2 feet and wound so as to give as even a temperature as possible from end to end. The 5-inch bars, which were placed in the centre of the furnace, were thus very evenly heated throughout their length, and tests showed that the variation in temperature did not exceed a few degrees. Bars of each steel were quenched in water from each tempering temperature, and other bars were cooled at a very slow rate (0·3° C. per minute) in order to produce the maximum brittleness. Izod test-pieces were then machined from the bars, impact tests carried out, and the Brinell hardness taken at each fracture end on the impact pieces.

The mean results are plotted in Figs. 7, 8, and 9.

Each of the steels is very susceptible to brittleness. The most interesting feature of the results is the rise in the impact value of the bars water-quenched above 650° C. in Steels NC and NR3 (Steel AH falls at 670° C., but might be expected to rise *between* 650° C. and 670° C.). This rise in impact value is accompanied by a fall in hardness due to the increased tempering effect as the temperature is raised (see Figs. 4 and 5). These experiments show that the higher the tempering temperature (provided the Ac1 critical range is not reached), the higher the impact value of the tough steel. Whenever the start of the allotropic change is reached, however, the impact figure falls again, and this fall is accompanied by a rise in hardness, showing that some solution of carbide in γ-iron has taken place at the tempering temperature, with subsequent formation of some martensite on quenching.

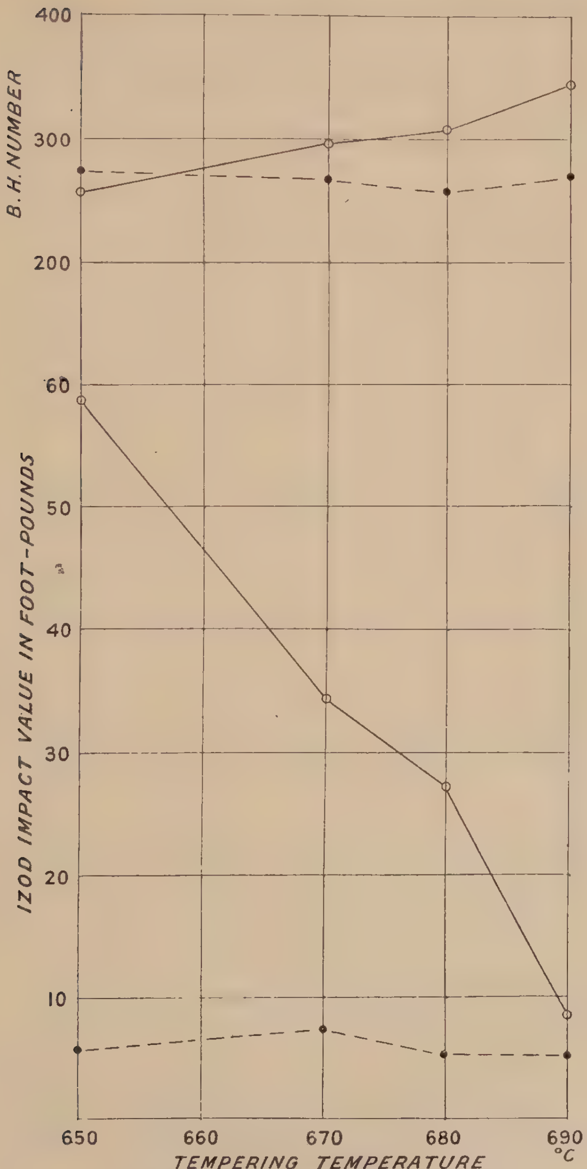

Fig. 7.—Nickel-Chromium Steel, AH.

Full line.—Bars quenched in water.
Dotted line.—Bars slowly cooled at 0·3° C. per minute.

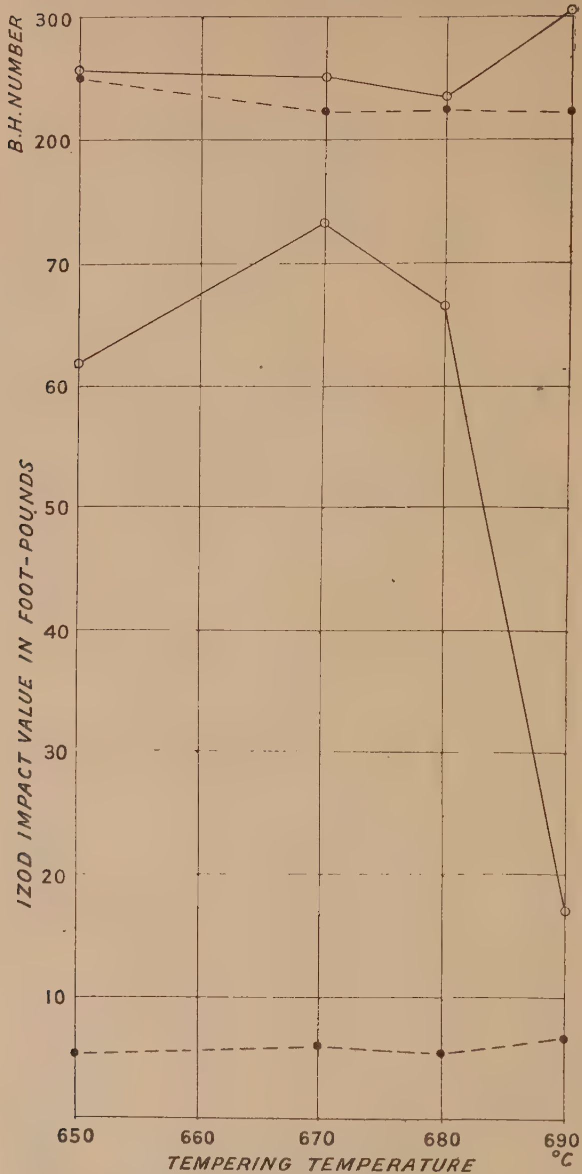

FIG. 8.—Nickel-Chromium Steel, NC.

Full line.—Bars quenched in water.
Dotted line.—Bars slowly cooled at 0·3° C. per minute.

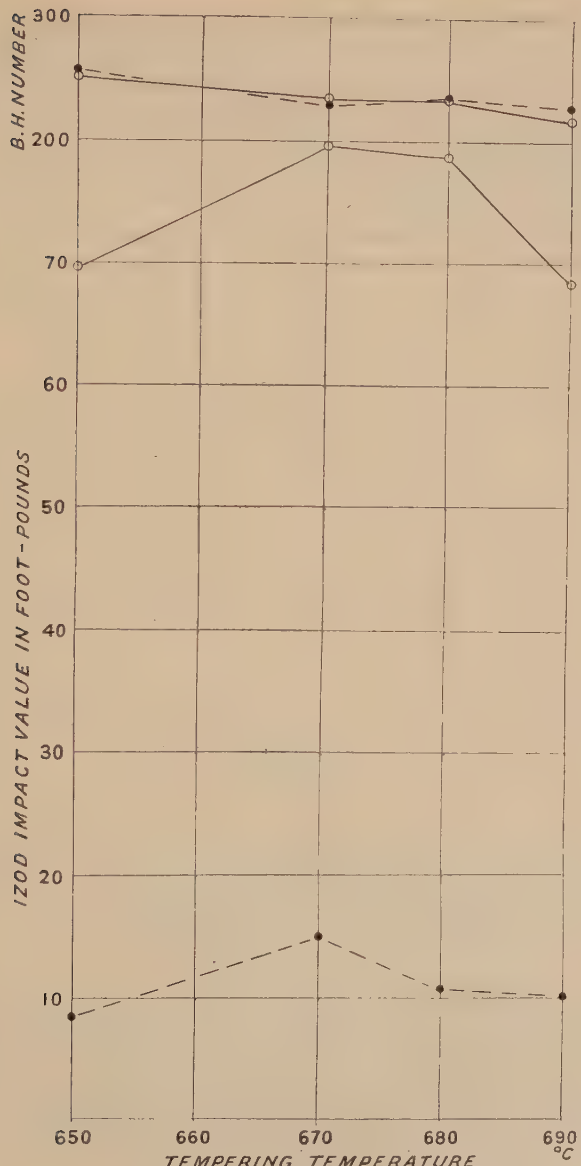

Fig. 9.—Nickel-Chromium Steel, NR3.

Full line.—Bars quenched in water.
Dotted line.—Bars slowly cooled at 0·3° C. per minute.

Fourth Series of Experiments.

The following ten steels were used in this series of experiments :

Five nickel-chromium, AH, NC, NR3, AW22, AW23 }
One plain carbon, A22 } As in previous series.
Two nickel, low and high phosphorus, NP1 and NP5 }
One chromium, AAX (C, 0·32; Mn, 0·91; Si, 0·145; P, 0·026; S, 0·027; Cr, 0·97 per cent.).
One high carbon, nickel-chromium, G2 (C, 1·50; Mn, 0·26; Ni, 3·46; Cr, 1·80 per cent.).

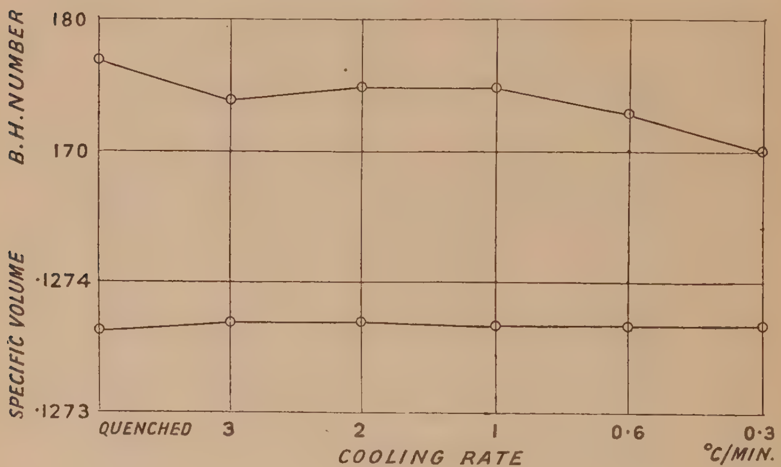

Fig. 10.—Carbon Steel, A22.

Specimens of these steels were treated with a view to producing the maximum amount of brittleness in order to obtain the maximum physical change. In each experiment the rate of cooling was 0·3° C. per minute.

Various tempering treatments were given before slow cooling was commenced. Steel G2 was quenched in oil from 1100° C. and the others from 850° C. before each treatment. The treatments and results are given in Table II., together with figures for the same steels quenched from a tempering temperature of 650° C. The results cannot all be conveniently presented graphically, but some have been plotted in Figs. 11, 12, and 13.

The results of experiments (2), (3), and (4) (Table II.) were at first very puzzling and disappointing in view of the absence of

any substantial change in any of the steels. Steel AW23 shows no change in specific volume of the nature found in the First Series of Experiments, although the hardness falls appreciably.

Consideration of the results after several failures to produce

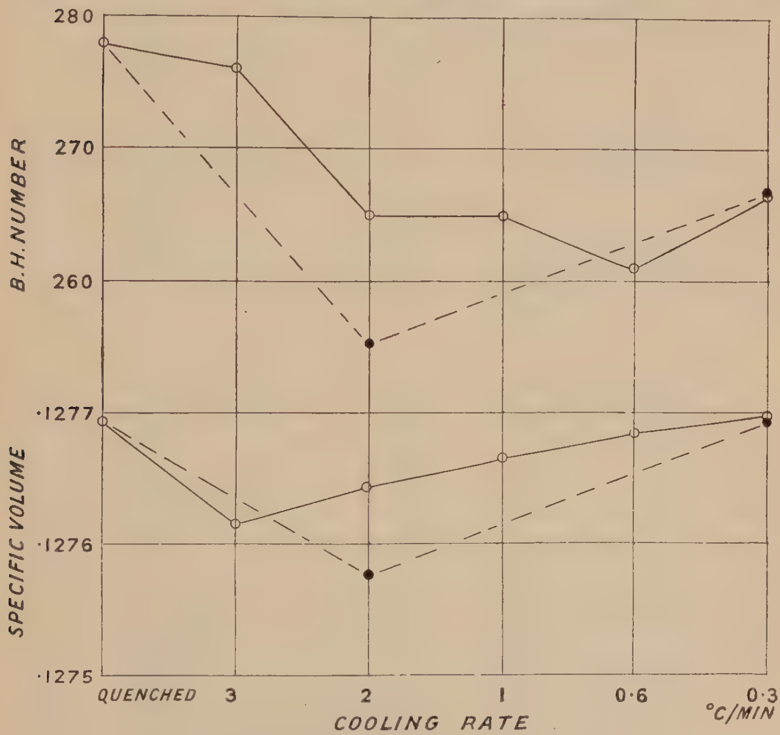

Fig. 11.—Nickel-Chromium Steel, AH.
Full line.—Specimens tempered at 650° C.
Dotted line.—Specimens tempered at 670° C.

a change in specific volume or hardness with very slow cooling led to the conclusion that an *intermediate rate of cooling* would show up a change, whereas very slow rates would not.

Another experiment (5) (Table II.) was carried out with the series of ten steels at a rate of cooling of 2° C. per minute, and the results fully confirmed this conclusion.

A marked change was not only produced in Steel AW23, but in *all* the nickel-chromium steels. Three specimens of Steel AW23 were

used in this experiment, and the results for the three agree remarkably. (Two of these three specimens were the identical specimens used in the First Series of Experiments.) The fall of specific volume in each case is very pronounced, but the hardness has not

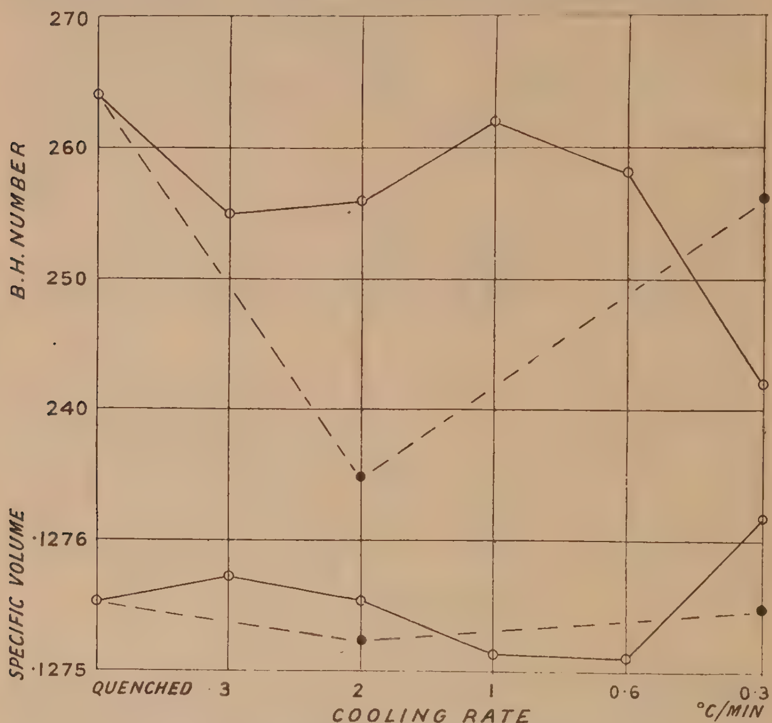

FIG. 12.—Nickel-Chromium Steel, NC.
Full line.—Specimens tempered at 650° C.
Dotted line.—Specimens tempered at 670° C.

altered. This must have been due to some solution of carbon in γ-iron at the soaking temperature. (Cooling curves have shown that when slight solution is induced at the commencement of the critical range in a steel of this composition a critical point on cooling is produced at about 100° C. This results in a hardening of the steel.)

It seemed remarkable that the changes in hardness with variation of cooling rate had not been previously noticed, but a

TABLE II.

Steel.	(1) Oil-hardened and Tempered 650° C. for Two Hours and Water-Quenched.		(2) Oil-hardened and Tempered 650° C. for Two Hours and Cooled at 0·3° C. per Minute.		(3) Oil-hardened and Tempered 670° C. for $2\frac{1}{2}$ Hours and Cooled at 0·3° C. per Minute.		(4) (3) Retempered 550° C. for Three Hours and Cooled at 0·3° C. per Minute.		(5) Oil-hardened and Tempered 670° C. for Three Hours and Cooled at 2° C. per Minute.	
	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.
AH	0·127694	278	0·127698	267	0·127693	266	0·127716	266	0·127577	252
NC	0·127556	264	0·127617	242	0·127559	256	0·127565	254	0·127524	235
NR3	0·127611	266	0·127602	263	0·127630	269	0·127596	270	0·127543	245
AW22	0·127490	257	0·127466	247	0·127481	252	0·127487	249	0·127337	235
AW23	0·127619	265	0·127592	230	0·127591	238	0·127613	235	0·127492 0·127482 0·127490	238 238 239
A22	0·127364	177	0·127368	170	0·127361	168	0·127361	170	0·127351	165
NP1	0·127330	198	0·127363	195	0·127296	192	0·127318	190	0·127153	196
NP5	0·127353	211	0·127288	201	0·127264	196	0·127303	196	0·127249	211
AAX	0·127625	261	0·127569	257	0·127631	215	0·127650	215	0·127620	228
G2	...	...	0·128120	401	0·128109	364	0·128063	331	0·128004	284

search of the published work showed that no hardness determinations had been made in experiments in which the effect of varying rates of cooling on the impact figure had been carried out. Later it was found that the changes in hardness are, in many cases, not very conspicuous when tempering temperatures of 650° C. or less

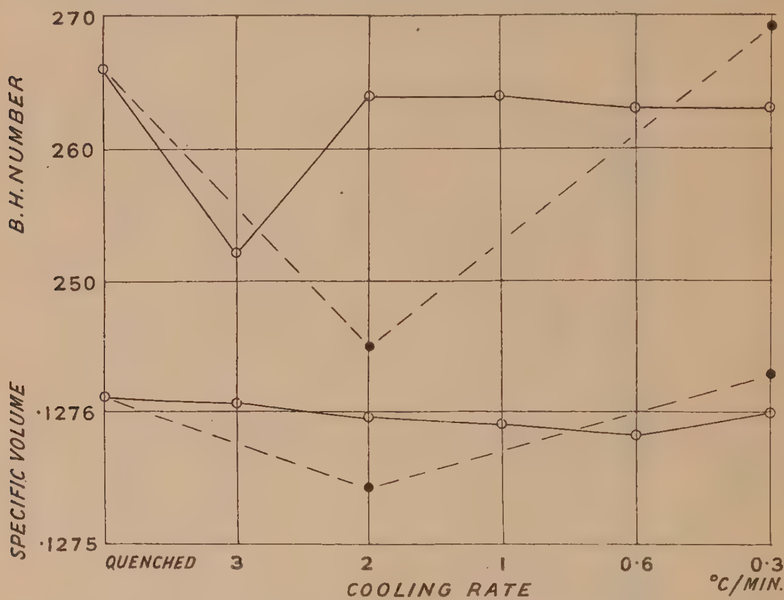

Fig. 13.—Nickel-Chromium Steel, NR3.

Full line.—Specimens tempered at 650° C.
Dotted line.—Specimens tempered at 670° C.

are used, and that the changes are often somewhat masked by the softening effect of extra-tempering.

In view of the well-established fact that the amount of brittleness is more or less directly proportional to the rate of cooling, it has previously been assumed that the physical change which produces the change in impact value would also be proportional to the rate of cooling. It now becomes evident from the present work that two changes giving opposite effects, depending on the rate of cooling, may take place in slowly cooled steels.

Also the fact that no appreciable change is revealed in density or in hardness when the tough state is compared with the fully

brittle state has led, naturally enough, to the false assumption that no change would be observable when intermediate rates of cooling were used.

The present work makes it apparent that the similarity in density and in hardness of the tough and the brittle states is merely accidental, and that in fact a considerable transformation takes place in the physical condition of the steels on slow cooling.

It is now clear that many of the results which have been attributed to the softening effect of extra-tempering must have been due, in part at least, to the change taking place in the "brittleness range" with intermediate rates of cooling. For example, Rogers,(6) using a rate of cooling of 1° C. per minute, obtained a softening in all his steels, in some cases the softening being considerably more than could be explained by extra-tempering, whereas Greaves and Jones,(2) using a rate of cooling of 0·3° C. per minute and equalising the tempering effects, showed that there was no difference in hardness between the water-quenched and the fully brittle condition. These results, which have previously been regarded as incompatible with each other, are now shown to be due to the difference in the rate of cooling employed, and the experimental results of these investigators agree completely with the observations made in the present investigation.

Fifth Series of Experiments.

The following seven steels were treated to find the effect of variation of cooling rate on the specific volume and hardness :

Three nickel-chromium, AH, NC, and NR3.
One plain carbon, A22.
Two nickel, low and high phosphorus, N3 (C, 0·29; Mn, 0·65; Si, 0·113; P, 0·036; S, 0·032; Ni, 3·22 per cent.), and NP5.
One chromium, AAX.

AW23, which had shown such a marked physical change in previous experiments, had unfortunately to be omitted from this series, together with AW22 and NP1, as sufficient of the steel was not available for all the experiments. NP1 was replaced by a fairly low-phosphorus nickel steel, N3.

Five sets of these seven steels were treated, after a preliminary oil-quenching from 850° C., as follows :

First Set.	Tempered two hours at 650° C. and quenched in water
Second Set.	„ „ „ „ slowly cooled at 3° C. per minute
Third Set.	„ „ „ „ „ „ 2° C. „
Fourth Set.	„ „ „ „ „ „ 1° C. „
Fifth Set.	„ „ „ „ „ „ 0·6° C. „

All the steels except N3 had been treated in the Fourth Series

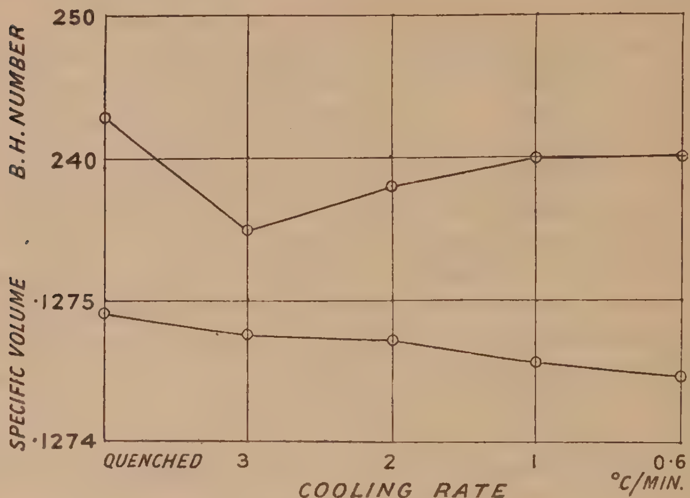

Fig. 14.—Nickel Steel, N3.

of Experiments at a cooling rate of 0·3° C. per minute. The results are plotted in Figs. 10 to 16.

The carbon steel provides a useful comparison for the others. Rate of cooling has no effect whatsoever on its specific volume, while the hardness falls slightly and practically continuously due to extra-tempering.

The fall in specific volume and in hardness in the nickel-chromium steels at intermediate rates of cooling is fully confirmed.

The changes in hardness are small, and are somewhat masked by the softening effect of extra-tempering. It is easy to see from these results how the variation in hardness with varying cooling rate has not been hitherto detected, as the standard tempering temperature has almost invariably been 650° C. or lower. When

the tempering temperature is raised to 670° C. the change in hardness is considerably accentuated, due, as previously indicated from the impact tests (Figs. 7, 8, and 9), to an increase in the condition of toughness above 650° C. and a consequent increase in the resulting physical change on cooling.

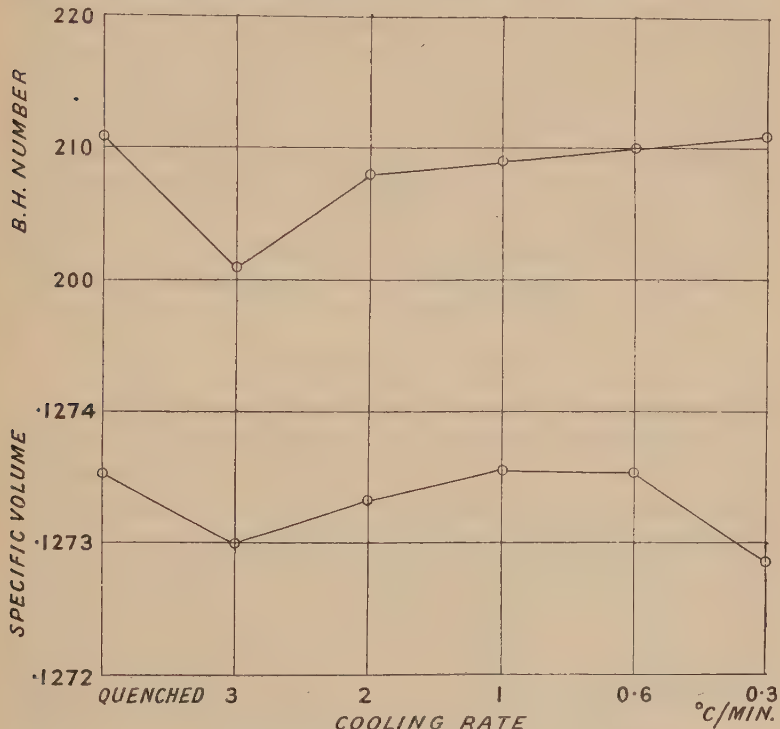

Fig. 15.—Nickel Steel (High Phosphorus), NP5.

Probably the most interesting and significant result of this series of experiments is the decided indication in the nickel steels and in the chromium steel of similar changes to those found in the nickel-chromium steels. The high-phosphorus nickel steel NP5 has been shown [4] to have a high susceptibility to temper-brittleness, and it shows (Fig. 15) changes both in specific volume and in hardness. Steel N3 (Fig. 14) shows a slight change in hardness only. Its susceptibility is not known, but is probably low. The change in specific volume is probably completely masked

by extra-tempering, which is considerable in nickel steels, as previously pointed out (First Series of Experiments).

The chromium steel is known to be susceptible to brittleness, and it shows an appreciable change in hardness, and possibly the indication of a change in specific volume (Fig. 16).

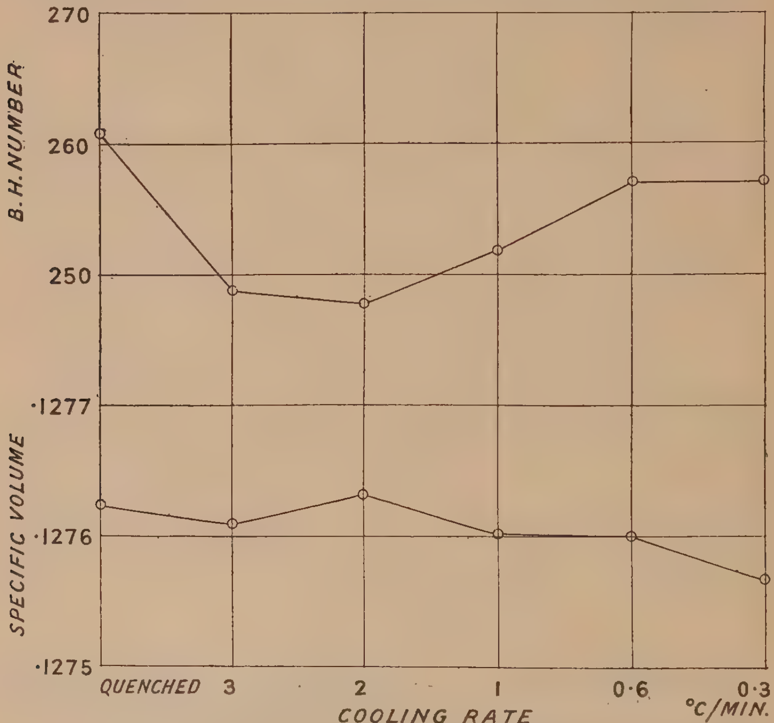

Fig. 16.—Chromium Steel, AAX.

The changes in all the steels are rendered even more significant when it is considered that they *oppose the effects of extra-tempering.*

That exactly the same physical changes are involved in all these steels of widely varying composition is an inevitable conclusion from these results, and that these are the physical changes involved in temper-brittleness is scarcely open to doubt. It is now clear that a substantial transformation takes place in steels susceptible to brittleness when they are slowly cooled from the tempering temperature.

It may also be said here that the condition of high hardness and high specific volume in water-quenched steels, as compared with the condition of low hardness and low specific volume in steels cooled at a moderate rate, is not evidently essential to reasonable toughness in the steels.

The moderate rates of cooling which produce a considerable contraction and softening in the steels may produce only a slight fall in the impact value. It is probable then that the toughness of a steel is dependent not nearly so much on any special condition of the steel which, in itself, gives toughness, as on the absence of the brittle condition which is induced by very slow cooling rates. The toughness is, of course, dependent, as has been previously shown, to a relatively small extent on a special condition giving added toughness to the steel by water-quenching.

Sixth Series of Experiments.

The five nickel-chromium steels already experimented with were used in a series of experiments to find the effect of tempering temperature on the tough state.

Specimens of Steels AH, NC, NR3, AW22, and AW23 were first oil-quenched from 850° C. and then tempered for six hours at 300° C. The specific volume and the hardness were determined and the tempering repeated (without intervening oil-quenching) at 400° C. The experiments were continued at various temperatures up to 670° C., six hours' soaking being given at each temperature, except at 670° C., where three hours' soaking was given in each of two successive treatments.

The results are plotted in Figs. 17 and 18.

No outstanding change is shown by any of the curves. It had been thought that a slight rise in specific volume might be observed as the temperature was raised through the brittleness range. No rise has taken place, but it is evident from some of the curves (notably Steel AH) that, whereas the hardness falls continuously, there are " halts " in the specific volume curves. The hardness falls continuously and evenly in all the steels, but the specific volume does not. From 450° C. to 650° C. in Steel AH the specific volume is almost unaltered in spite of a softening of 100 Brinell. A similar halt is seen in the other steels at about

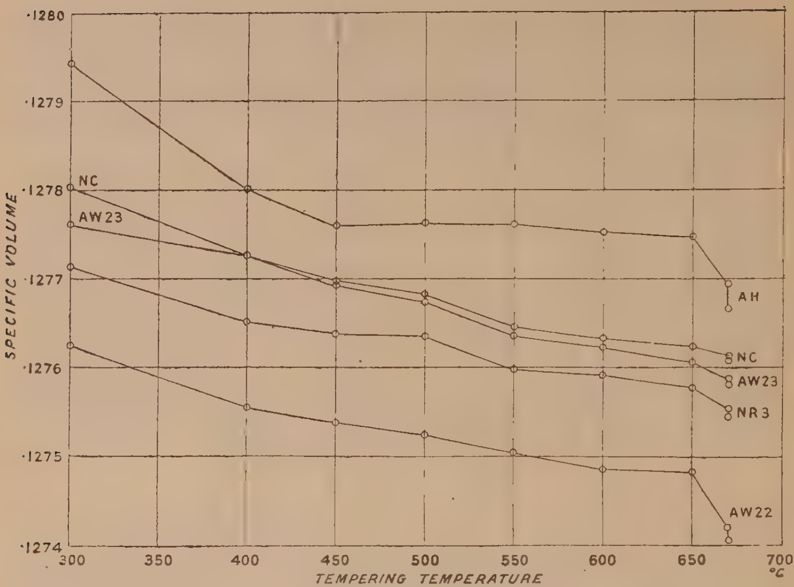

Fig. 17.—Five Nickel-Chromium Steels.

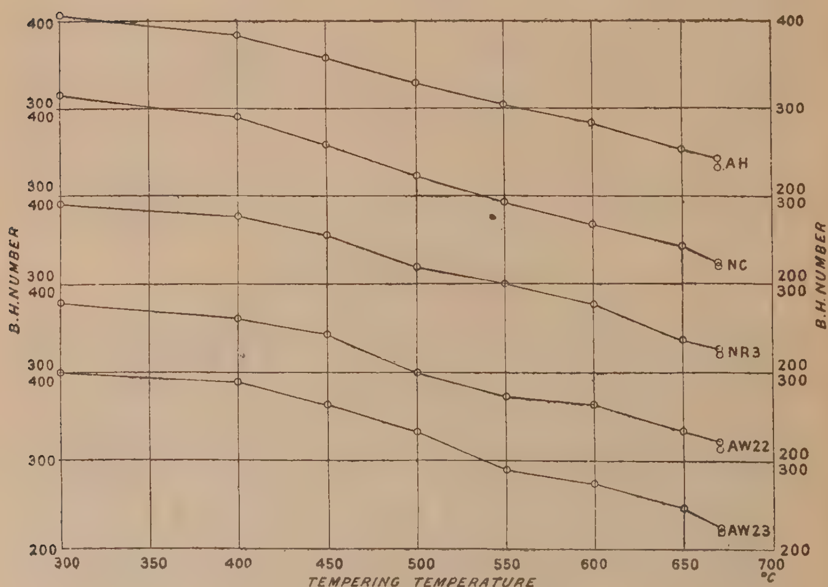

Fig. 18.—Five Nickel-Chromium Steels.

600° C. to 650° C. There is no sign of secondary hardening in any of the steels, and it is possible that an increase in the tough state with temperature tends to increase the specific volume. The specific volume, while it does not rise, opposes the contraction one would expect from the extra-tempering received by the steels.

The curves give further proof of the very small effects of extra-tempering in nickel-chromium steels at high tempering temperatures. It will be noted that the extra three hours' heating at 670° C. gave a very small fall in all the steels.

Steels AH, NR3, and AW22 show a much larger fall in specific volume between 650° C. and 670° C. than between any of the preceding temperature intervals. This effect must be due to globularisation at high temperatures, and is further proof that the state of division exerts a decided effect on the specific volume of a steel.

Seventh Series of Experiments.

A Possible Explanation of the Observed Physical Changes.

In connection with some experiments which had been carried out by the present authors in an investigation into the behaviour of special steels in the Ac1 critical range, a result had been obtained in a nickel steel which, it was thought, might throw light on the physical changes which had been found to take place in special steels in the "brittleness range."

The nickel steel concerned was Steel N3, which was used in the Fifth Series of Experiments. Bars of this steel had been heated at 695° C. until complete solution of carbide had taken place. Certain bars were quenched in water after this treatment, and others were slowly cooled at a very slow rate (0·3° C. per minute) to 400° C. Tensile and Izod test-pieces were machined from the bars and mechanical tests carried out.

Examination of a micro-specimen, which had been placed in the furnace along with the bars to follow the heat treatment, showed that the carbide of the slowly cooled steel had separated out in a remarkably complete film round the grain boundaries. A micrograph of this is shown in Fig. 20 (Plate XVIII.). It was noticed also that the hardness of the micro-specimen was unusually high—

considerably higher than would be expected in an annealed steel of this composition.

When the Izod impact test-piece, which had been subjected to the same treatment as the micro-specimen, was broken, it was found that the impact value varied in a manner not obtained in any of the many other bars subjected to other treatments. When the hardness at the fracture faces was taken it was found to vary also from one end of the bar to the other, and to be higher than what was expected in the annealed state.

It was thought that the effect of variation in physical properties

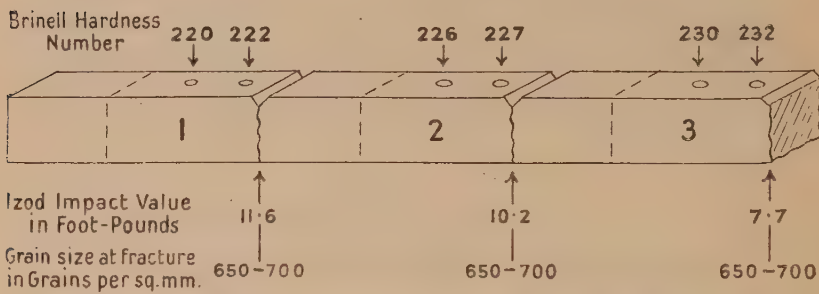

Fig. 19.—Diagrammatic Sketch of Izod Impact Test-Piece of Nickel Steel containing Grain-Boundary Carbide. For specific volume of specimens, see Table III.

(The notches are drawn all on one face to avoid confusion. In the actual test-piece they were cut on three different faces.)

of this steel containing grain-boundary carbide might provide an analogy to the behaviour of the special steels in the brittleness range. The test-bar and micro-specimen were consequently subjected to a number of experiments.

A diagrammatic sketch of the Izod impact test-piece referred to is shown in Fig. 19. The manner in which the impact value and the hardness varied from one end of the bar to the other (and inversely to each other) is clearly indicated.

The following experiments were carried out :

(*a*) Microsections were prepared at each of the fracture faces, and the polished sections were boiled in sodium picrate to etch up the carbide. It was found that the amount of carbide round the grains varied along the length of the bar in a similar manner to the impact figure and the hardness. As the impact value

decreased and the hardness increased, the boundary became more apparent. The original micro-specimen, which had a higher hardness than any part of the test-piece, had a more complete boundary film than any part of the latter. The variation of the amount and completeness of the boundary in the different specimens was clearly beyond doubt. This observation was confirmed by an independent observer, who placed the specimens in the same order as the authors.

The grain-size of each specimen was estimated and found not to vary. The possible influence of variation in grain-size was thus eliminated.

(*b*) Specific volume test-pieces were then taken from each fracture end of the test-bar and from the original micro-specimen, and the specific volume determined. It was found that the specific volume was also much higher than would be expected in the annealed state. See Table III.

TABLE III.—*Seventh Series of Experiments.*

Specimen.	Experiment (*b*). Grain Boundary Condition.		Experiment (*c*). Tempered Fifteen Minutes at 650° C.		Experiment (*d*). Retempered One Hour at 650° C.		Experiment (*e*). Annealed at 760° C.	
	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.	Specific Volume.	Brinell Hardness.
1	0·127427	220	0·127372	177	0·127265	166	0·127375	198
2	0·127479	226	0·127389	191	0·127279	164	0·127356	201
3	0·127456	230	0·127395	194	0·127284	168	0·127395	203
4	0·127458	243	0·127363	183	0·127270	176	(not treated)	...

(*c*) The four specimens were then tempered at 650° C. for fifteen minutes and cooled quickly in the furnace. The specific volume and the hardness after this treatment were both much lower, and micro-examination showed that *the grain boundary was largely broken up* into small globules. This was the only apparent change in structure, and the difference in properties seemed to be attributable only to the state of distribution of the carbide.

(*d*) The specimens were retempered at 650° C. for one hour, and this treatment resulted in a further decrease in specific volume and in hardness, and the grain boundary was *completely destroyed*. The arrangement of the larger globules which had

been formed by globularisation from the carbide of the boundary indicated faintly in parts the original granular structure.

(*e*) Three of the specimens were then quickly annealed by heating to 760° C. for a few minutes and cooling quickly in the furnace. The results show (Table III.) that the specific volume and the hardness are much lower than when the carbide was obtained at the boundaries in the same specimens—Experiment (*b*). It would be expected that the steel cooled more quickly from above the Ar1 point and from a higher temperature would show a higher hardness and possibly a higher specific volume. The opposite, however, is obtained. The steel cooled extremely slowly has much the higher specific volume and hardness, and the only apparent physical difference between the two structures produced is in the distribution of the carbide round the boundaries in the slowly cooled steel and the production of the usual mixture of ferrite and pearlite in the other.

It is easy to see why a steel with a network of hard carbide completely surrounding the grains should give a higher hardness than the same steel with the carbide distributed in a fine state of division throughout the mass. In the first case the hard network surrounding the grains will interfere with the flow of the iron matrix in a decisive manner, whereas, with a homogeneous mixture of carbide and iron, the flow of the matrix is not restricted by any such interference.

A tensile test-bar having the carbide distributed as a network round the grains gave a tensile strength of 56·4 tons per square inch and an elongation of 9·0 per cent. The figures supplied by the makers for this steel were 55 tons per square inch tensile strength and 20 to 25 per cent. elongation (oil-hardened 820° C. and water-tempered 620° C.). These figures may not be strictly comparative, but it is evident that the grain boundary has not produced any great difference in the tensile strength. The elongation is lowered by about half, but the difference in Izod values is much greater. The Izod value for the grain boundary bar was 9·8 foot-pounds, whereas in the oil-hardened and water-tempered state it was given as 60 foot-pounds. There is thus the strong indication that the distribution of the carbide at the grain boundary has a much greater effect on the impact value than on the other mechanical properties.

Final Consideration of Results.

It has been clearly proved that in steels susceptible to temper-brittleness a moderate rate of cooling (2° C. or 3° C. per minute) produces a considerable fall in specific volume and in hardness. The moderate rates of cooling which produce this physical change are known to produce comparatively small variations in impact value.

It is evident that the magnitude of this physical change is proportional to the degree of brittleness which may be produced by very slow cooling. Thus in nickel-chromium steels, which have a high susceptibility to brittleness, the change in specific volume and in hardness is very marked, whereas in nickel and in chromium steels which have a low susceptibility the change is small. As the phosphorus content of a nickel steel is raised the change is accentuated.

This physical change, as has been previously pointed out, may be explained by the deposition, on moderately slow cooling, of a solute which is in solid solution in the steel at the tempering temperature and which is retained in solid solution by quick cooling. The only possible solute which is present in all the steels in sufficient quantity to give the substantial physical changes observed is carbide (either simple carbide of iron or double carbide of iron and chromium). Impurities which are present in the steels in small quantities may act along with the carbide, but in themselves could not give rise to the large changes observed, particularly in the nickel-chromium steels.

It is thus suggested that a certain amount of carbide is present in solid solution in α-iron (which may be nickel or chromium ferrite) at high tempering temperatures, and that this carbide is, partially at least, deposited in a fine state of division throughout the mass on moderately slow cooling.

The suggestion of Rogers [(6)] that brittleness is due to solution and redeposition of carbide is thus regarded by the authors as being partially true, but it is necessary to assume a further change in order to explain fully the results obtained in the present investigation.

The amount of carbide held in solid solution at the high temperature probably varies considerably with the composition

of the steel, and also may increase considerably with increase in temperature, especially near to the Ac1 range. This certainly seems to be indicated by the rise in impact value found in the nickel-chromium steels above 650° C. Incidentally, the authors consider it possible that increase of solution of carbide in α-iron (which is, in these steels, really ferrite containing nickel and chromium in solid solution) may be responsible for the inception of the start of the Ac1 change at a lower temperature. The reactions which take place in the Ac1 critical range have been investigated by the authors and will be the subject of a separate publication.

It would appear that there is a tendency for certain special elements, such as nickel, manganese, chromium, and phosphorus, to increase the solubility of carbide in ferrite at temperatures near to the Ac1 range and to redeposit it from solution at lower temperatures on slow cooling. On the other hand, the addition of a small quantity of molybdenum is believed by the authors to eliminate brittleness by effecting the retention of carbide in solid solution in α-iron no matter what be the rate of cooling.

The deposition of carbide from solid solution will not, however, in itself produce any great degree of brittleness in a steel, and it is evident from the present work that another physical change is induced in the steels by very slow rates of cooling. It has been clearly proved that very slow rates of cooling give a considerable increase in the specific volume and in the hardness when compared with the values obtained by moderate cooling rates. This increase in specific volume and in hardness cannot be explained merely by a further deposition of carbide when the rate of cooling is slower, although it is probable that the slower the rate of cooling the more complete will be the deposition of carbide from solid solution.

The authors believe that the state of distribution of the carbide must be the predominating influence in this increase in specific volume and in hardness, and also in the production of the high degree of brittleness which accompanies it.

The evidence provided by the experiments on a nickel steel containing grain-boundary carbide (Seventh Series of Experiments) points strongly to the fact that, when the carbide is distributed round the grain boundaries, the specific volume and the

hardness are considerably raised over the values obtained for these properties in the same steel with the same amount of carbide present but distributed more or less homogeneously throughout the mass. The grain-boundary condition results also in the production of brittleness in the steel, whereas the steel in its normal quenched and water-tempered condition is tough.

These experiments give, therefore, a complete analogy to the physical changes observed in steels susceptible to temper-brittleness and provide a reasonable explanation of the variations in impact value.

The rise of specific volume and of hardness on cooling very slowly from the tempering temperature is believed to be due to the expulsion of the carbide, which is deposited out of solution, to the grain boundaries. If a complete network of carbide is formed during cooling it is not difficult to see how it would affect the physical properties to such a marked extent. The actual grains of the steel will become virtually separated from each other by the network of carbide, and the coefficient of contraction of the latter will exercise a determining influence on the final volume of the mass. It is probable that the coefficient of contraction of carbide is smaller than that of iron, and consequently a greater volume of the mass would be obtained. The effect of the carbide network on the hardness is clearly explainable by its interference with slip or flow of the mass of the steel. No such interference takes place when the carbide is distributed evenly throughout the mass.

Microscopical examination of the steels used in the present work has not yet produced complete confirmation of the above theory. It is probable that any grain boundary which is produced is extremely small in magnitude and therefore difficult of detection. The grain boundary which was found in the nickel steel (Fig. 20) was easily detected by etching in sodium picrate, but was extremely difficult to pick out by ordinary etching—in fact, its existence could not have been established at all had it not been possible to etch up the carbide in the polished specimen. The grain boundary in this case must be much larger than any which is produced in the tempering zone in steels susceptible to temper-brittleness. In the nickel-chromium steels, which have

high susceptibilities, it has not yet been found possible to etch up the carbide in the polished specimens.

In the high-phosphorus nickel steel, however, the polished specimen was etched by sodium picrate and an unmistakable grain-boundary was revealed. This is exactly similar in structure, but not so apparent, as the grain boundary shown in Fig. 20. There is also a faint indication of a boundary in the low-phosphorus nickel steel. This encourages the authors to believe that they may yet be able to prove the existence of a carbide grain boundary in all the slowly cooled steels by direct demonstration. Meanwhile the microscopical structure of the steels is being further investigated.

The effect of the state of aggregation of the carbide (apart altogether from the effect of its distribution round the grain boundaries) may be commented on.

The results have shown that the fall in specific volume in carbon steels with rise in tempering temperature is comparatively small, but that it is very pronounced in nickel steels and also appreciable in nickel-chromium steels. This effect must be due to globularisation of the carbide, which micro-examination has shown to be slow in carbon steels but which becomes very rapid in nickel steels as the temperature is raised to near the critical range.

It has been pointed out by other investigators [14] that globularisation of carbide can only be explained by assuming a certain solubility of the carbide in α-iron. The rate of globularisation must then depend on the degree of solubility of the carbide in the α-iron (other factors, such as initial state of division and temperature, being equal). It thus appears probable that the increased rate of globularisation in a nickel steel is a proof, in itself, of the previous contention of the authors that the addition of nickel increases the amount of carbide which is held in solid solution in the ferrite at higher temperatures. As the rate of globularisation increases until the Ac1 critical range is reached, so also must the amount of carbide present in solid solution increase. Similar reasoning applies to the effect of other elements besides nickel.

The contraction in the nickel steels as the tempering temperature is raised (Figs. 2 and 3) is surprisingly large, but it seems

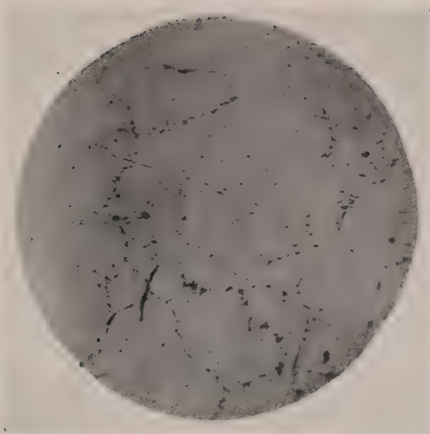

FIG. 20.—Nickel steel, N3. Etched in boiling sodium picrate. $\times 370$.

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certain that globularisation must account for it entirely. The results in Table III. provide further confirmation of the remarkable changes in specific volume (and also in hardness) which can be brought about by tempering nickel steels at high temperatures.

This investigation into the physical changes concerned in the phenomenon of temper-brittleness is being continued at present, and further experimental results, particularly in regard to magnetic properties and resistivity, will be published in due course.

Summary.

Specific volume and Brinell hardness determinations have been carried out on various steels, in their tough and brittle states.

From the data obtained it has been clearly shown that variations, depending on the rate of cooling from the tempering temperature, are produced in these characteristic properties.

An explanation has been advanced to account for the phenomenon of temper-brittleness. It has been suggested that α-iron (ferrite) may, at higher tempering temperatures, dissolve an appreciable amount of carbide which, on quenching, is retained in solid solution. On slow cooling, however, the carbide is re-deposited at the grain boundaries, giving rise to a brittle network throughout the mass.

The effect of special elements on the physical properties and microstructure has been dealt with at some length.

Mr. Dickie desires to express his indebtedness to the Executive Committee of the Carnegie Trust (for the Universities of Scotland) for the award of a Research Scholarship.

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THE CONSTITUTION OF THE IRON-SILICON ALLOYS.*

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One of the first constitutional diagrams that Tammann [1] constructed by the method of thermal analysis was that of the iron-silicon alloys. According to the diagram, only one intermediary phase is present. This phase was found to correspond to the formula FeSi. Tammann [2] has pointed out that only this compound exists, and that the many "compounds" found by chemical analysis of residues do not enter into consideration.

There are, however, some observations published which are irreconcilable with Tammann's diagram. Pick [3] has observed crystals the composition of which correspond to the formula $FeSi_2$. Lowzow [4] also has observed these crystals; he is, nevertheless, of the opinion that the compound $FeSi_2$ does not occur in normal ferro-silicon. Kurnakow and Urasow [5] have determined the freezing-point diagram once more. They state that the alloys with a silicon content between 55·2 per cent. and 61·5 per cent. solidify to a homogeneous phase.

Some years ago a preliminary report of an X-ray investigation of this system was published.[6] A recent work by Bamberger, Einerl, and Nussbaum [7] should also be mentioned.

In alloys containing 23 to 30 per cent. of silicon, Murakami [8] observed a phase forming on cooling at 1020° C. by reaction in the solid state.

The discrepancies between the results of previous investigators have been the motive for an X-ray investigation. The well-known troubles with technical 50 per cent. ferro-silicon impart a special interest to the question of the existence of a compound $FeSi_2$.

To the X-ray investigation is appended a series of micrographs. On the other hand, the author has not repeated the thermal analysis. It is evident from the investigation of Kurnakow

* Received June 15, 1926.

and Urasow that in order to obtain further information concerning the equilibrium diagram at 50 per cent. it is necessary to reduce the errors of the thermal determinations to a few degrees. The platinum—platinum-rhodium thermocouple is, however, very sensitive to the silicon vapour, and the desired accuracy is difficult to attain. It also seems probable that undercooling might disturb the thermal analysis.[5, 7, 9]

The alloys investigated were prepared from electrolytic iron

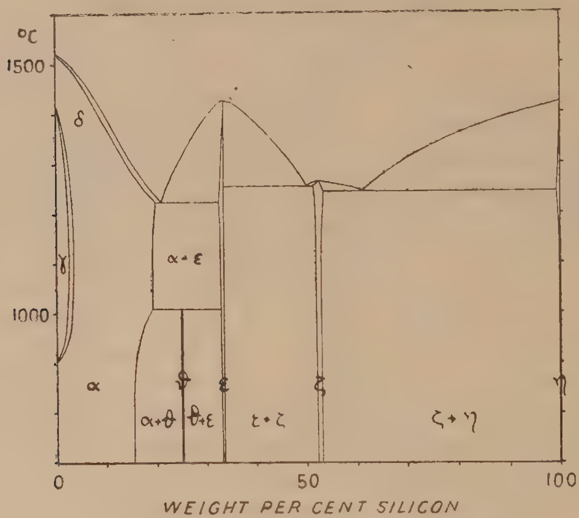

Fig. 1.—Iron-Silicon Equilibrium Diagram.

and silicon, the latter containing 0·15 per cent. of aluminium. They were melted in a vacuum furnace fitted with a carbon tube heating element. Porcelain, and in some cases magnesia, crucibles were used; the corrosion of the porcelain crucibles by the molten alloys was inappreciable. The melts were crushed and remelted to secure homogeneity.

The equilibrium diagram (Fig. 1) has been derived from the results of the present investigation combined with the previously published results. The notation of the phases is also evident from the diagram.

In Fig. 3 (Plate XIX.) a series of X-ray photograms is reproduced. In order to obtain sharp lines, the powdered alloys were

reheated *in vacuo* to 1100° C. and cooled in the furnace.[10] The existence of three intermediary phases is evident from the X-ray photograms. It is also evident that the compositions of the phases ε and ζ correspond approximately to the formula FeSi (33·5 per cent.) and $FeSi_2$ (50·2 per cent.). The composition of the θ phase is more difficult to compute, in consequence of the fact that the θ phase is always followed by the α phase.

It is well known that the ε phase crystallises in tetrahedra (Fig. 4, Plate XX.). X-ray investigation of such tetrahedral crystals has given the result that the symmetry group is T^4, and the number of atoms in the elementary cube is 8. The ζ phase crystallises in plates (Fig. 5). These crystals proved to be tetragonal (C^1_{4h}), with three atoms in the elementary parallelepiped. For the ε and ζ phases it has also been possible to determine the atomic grouping.[6] The crystal structure of the θ phase has not yet been revealed; the powder photogram is very complicated, and it has not been possible to prepare single crystals.

The lattice parameters of a solid solution, and consequently the angles of X-ray deflection, are functions of the composition. This fact is clearly to be observed as regards the lines of the α phase in Fig. 3. The parameter of the centred cubic lattice as derived from these photograms is found in Table I., and its relation to the silicon percentage is represented graphically in Fig. 2. Here also are tabulated the densities and the computed numbers of atoms in the cube considered. The number is found to be two; the differences found are those to be expected, if the surface layer of the powder grains has lost some silicon on annealing.

From these results it must be concluded that in the α-iron lattice the silicon atoms replace the iron atoms. X-ray investigation on single crystals has proved that if the silicon exceeds about 7 per cent. the distribution of the replacing silicon atoms approximates to a regular one, as they form a face-centred cubic lattice with a parameter double that of the α-iron lattice.[11]

The crystal structure of α-iron and of δ-iron is the same, and it has been pointed out that the δ-range may be regarded as a continuation of the α-range.[12] It is known that silicon raises the α–γ and lowers the γ–δ transformation points to a considerable

degree.[9, 13] In alloys with more than 2 per cent. of silicon no transformation is to be detected by thermal analysis. This

TABLE I.

Phase.	Silicon. Per Cent.	$a \cdot 10^8$. Centimetres.	Density Observed.	Number of Atoms.
α	0	2·861	7·85	1·996
,,	3·5	2·857	7·67	2·009
,,	7·1	2·845	7·49	2·003
,,	10·8	2·834	7·33	2·007
,,	13·5	2·823	7·23	2·000
,,	20·1	2·815	...	...
,,	22·4	2·814	...	...
,,	25·0	2·815	...	...
ϵ	22·4	4·479	...	...
,,	25·0	4·480	...	...
,,	33·6	4·478	6·05	7·85
,,	35·0	4·469	...	...
,,	42·0	4·469	...	...
ζ	42·0	2·687 5·127	...	...
,,	50·5	2·687 5·127	4·74 (?)	2·84
,,	65·0	2·679 5·120	...	...
η	65·0	5·419	...	...
,,	100	5·419	...	(8)

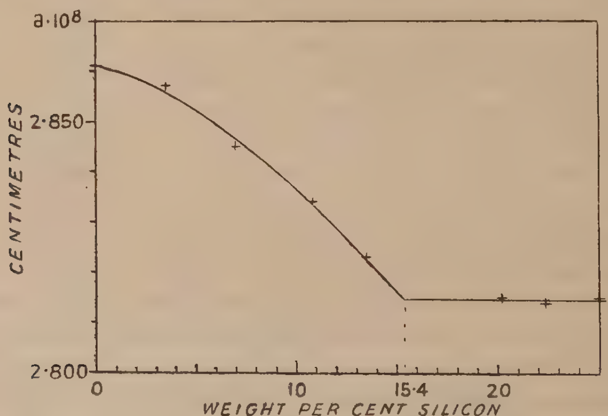

FIG. 2.—Lattice Parameter of the α Phase.

fact has been accounted for by the assumption that the transformation interval is considerably extended. Not long ago

FIG. 3.—Powder photograms of iron-silicon alloys. Fe-K radiation.

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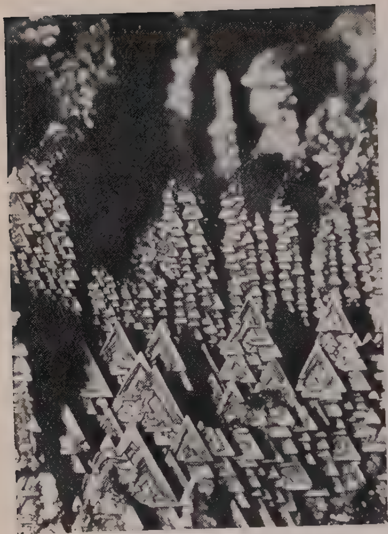

FIG. 4.—Crystals of the ε-phase. ×2.

FIG. 5.—Crystals of the ζ-phase. ×2.

FIG. 6.—16·8 per cent. Si. α-grains with θ in the boundaries. Etched with $HF+HNO_3$. ×200.

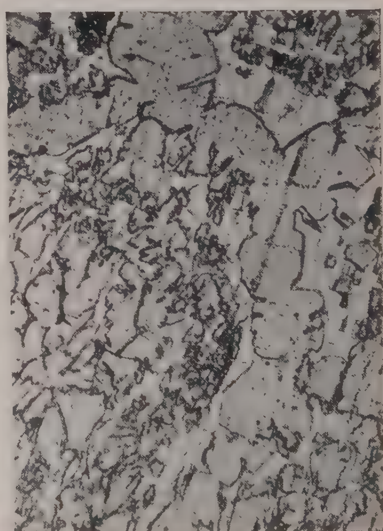

FIG. 7.—20·1 per cent. Si. α-grains from which θ has separated. Etched with $HF+HNO_3$. ×200.

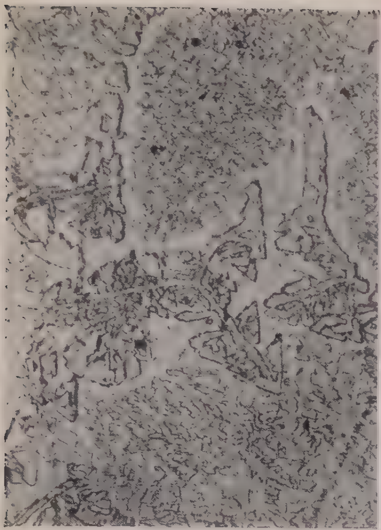

FIG. 8.—20·8 per cent. Si. α-grains with θ. In the boundaries eutectic α-ε. Etched with HF+HNO_3. ×200.

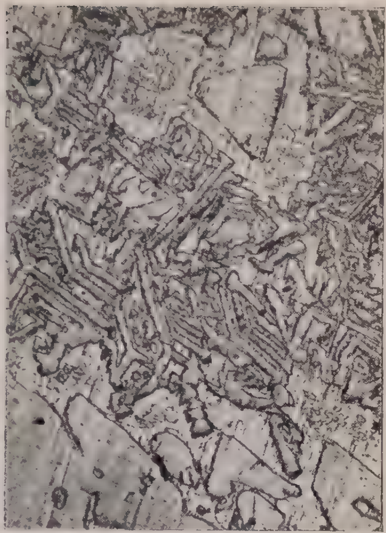

FIG. 9.—22·4 per cent. Si. Primary ε-crystals and eutectic α-ε. Etched with HF+HNO_3. ×200.

FIG. 10.—Same material as Fig. 9. ε-crystals, primary and eutectic, surrounded by θ. Etched with HF+HNO_3. ×400.

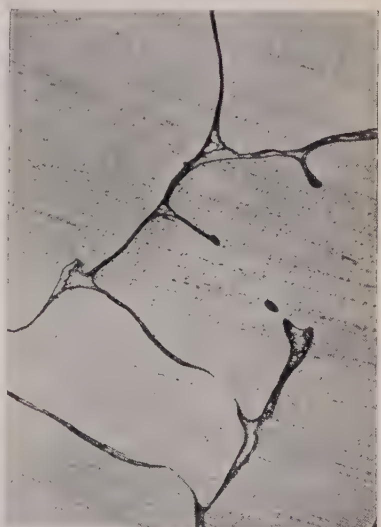

FIG. 11.—32·8 per cent. Si. ε-phase with a little α and θ. Etched with HF+HNO_3. ×200.

FIG. 12.—36 per cent. Si. ε (dark) and ζ (white, hard constituent). Etched with $HF+HNO_3$. ×200.

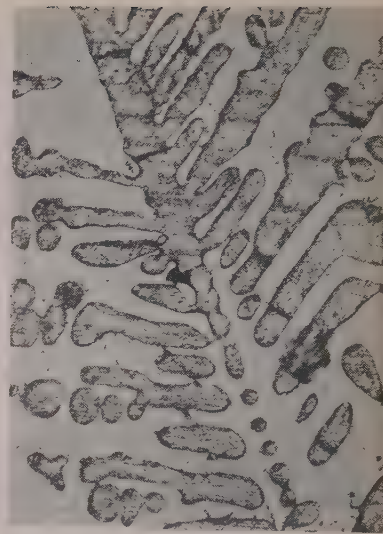

FIG. 13.—Approx. 45 per cent. Si. ε-dendrites in ζ. Etched with $HF+HNO_3$. ×100.

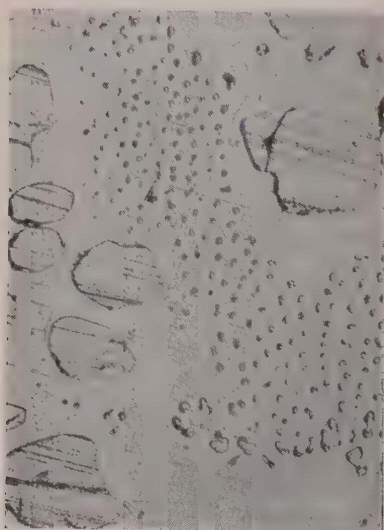

FIG. 14.—49 per cent. Si. Primary ε-crystals and eutectic ε-ζ. Etched with $HF+HNO_3$. ×200.

FIG. 15.—50·5 per cent. Si. Eutectic ε-ζ. Etched with $HF+HNO_3$. ×100.

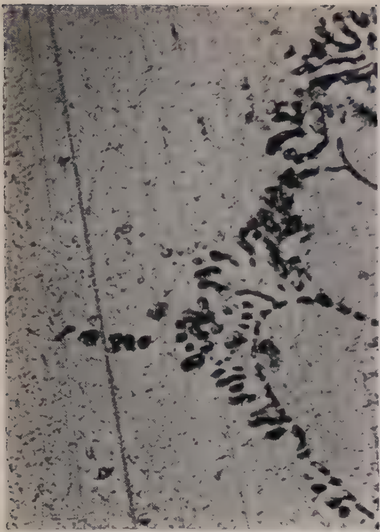

FIG. 16.—52·5 per cent. Si. ζ with traces of ε. Etched with $HF+HNO_3$. $\times 200$.

FIG. 17.—Approx. 65 per cent. Si. Primary crystal lamellae of η and eutectic ζ-η. Etched with $HF+HNO_3$. $\times 200$.

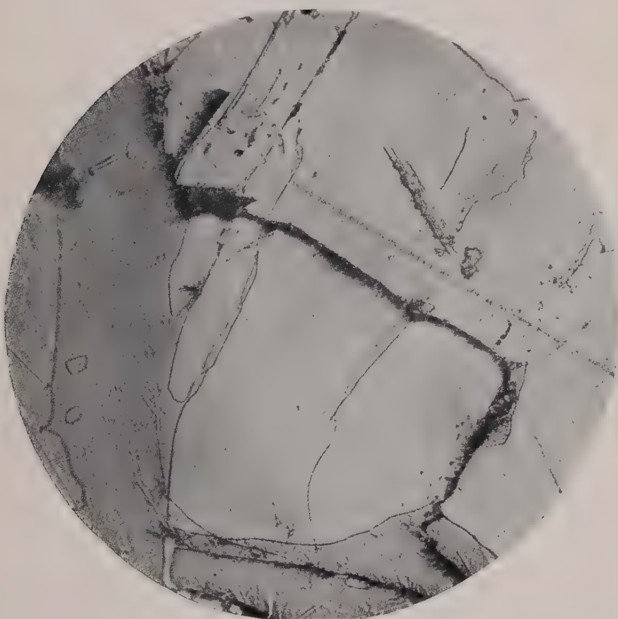

FIG. 18.—Primary crystal lamellae of η and thin ones in the eutectic ζ-η. Unetched. $\times 400$.

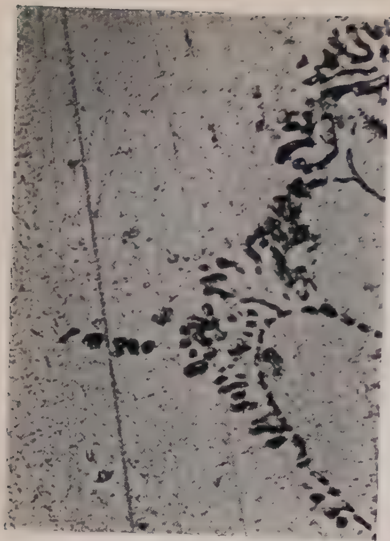

FIG. 16.—52·5 per cent. Si. ζ with traces of ε. Etched with $HF+HNO_3$. $\times 200$.

FIG. 17.—Approx. 65 per cent. Si. Primary crystal lamellae of η and eutectic ζ-η. Etched with $HF+HNO_3$. $\times 200$.

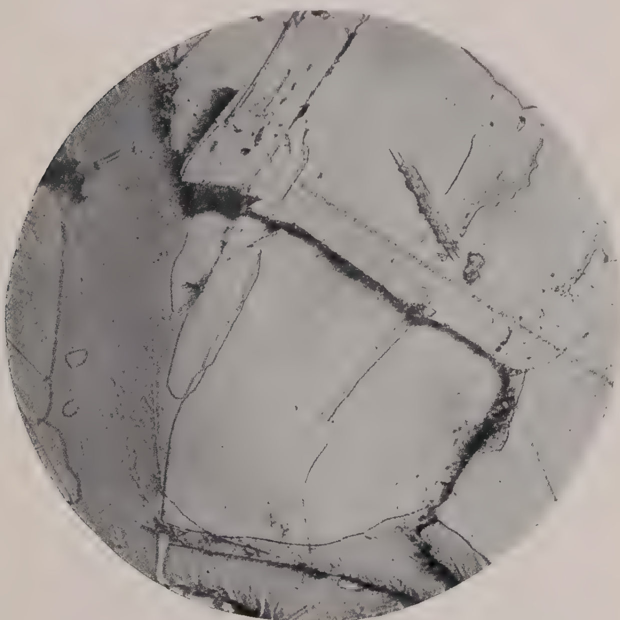

FIG. 18.—Primary crystal lamellae of η and thin ones in the eutectic ζ-η. Unetched. $\times 400$.

Oberhoffer [14] put forward the hypothesis that the presence of sufficient silicon makes the γ-range disappear and the α- and δ-ranges unite, as is shown in Fig. 1. X-ray investigation of the very coarse grains (which were often more than a centimetre in diameter in melts of 50 grammes) proved these grains to be true crystal individuals if the silicon content be more than 3·5 per cent.[11] Thus no δ–γ or γ–α transformation occurs, which fact fully substantiates the correctness of the hypothesis of Oberhoffer.

The composition of the ε phase approaches very closely to that corresponding with the formula FeSi—that is, 33·5 per cent. of silicon; in fact, an alloy with 32·8 per cent. of silicon shows a little α and θ (Fig. 11, Plate XXI.). An alloy with 33·6 per cent. of silicon shows rare traces of ζ. All the previous investigators have considered the ε phase as one of invariable composition, yet from the X-ray photograms it is evident that the lattice parameter is variable (Table I.), and it must be concluded that the composition is variable within a narrow range. This may also be expressed thus: the compound FeSi is capable of dissolving a little of one or both the components. The most probable assumption is that the solubility is effected by simple substitution; the lattice shrinks when the silicon content increases, and the silicon atom is known to be smaller than the iron atom. A closer investigation has not been possible because of the narrowness of the range of homogeneity.

The absence of the ζ phase in Tammann's diagram must be supposed to be partly due to the fact that a temperature difference between the eutectic points ε–ζ and ζ–η is scarcely observable. Another important cause is probably the difficulty of grinding microscopic sections of alloys containing about 50 per cent. of silicon. When small melts of this composition are melted under carbon monoxide they absorb a considerable quantity of the gas, and on solidification become spongy. Even if they are melted *in vacuo* in porcelain crucibles, the melts do not hold together very well, perhaps owing to intergranular layers of silica. The result is a little better if the alloy is melted in a magnesia crucible and the temperature raised to the "boiling point" of the alloy, but then it is difficult to obtain the desired silicon content.

Certainly the difficulty of grinding is the cause of the mistake

of Kurnakow and Urasow, that the homogeneity range of this phase should extend up to 61·5 per cent. of silicon. They never detected the thin lamellæ of η in the eutectic ζ–η (Figs. 17 and 18, Plate XXIII.). To prepare good microscopic sections of these alloys the usual grinding on emery-paper must be avoided; the method followed is that generally employed to prepare petrological microscopic sections. Their preparation is completed by polishing with rouge on the "pitch plate."

On a polished surface the eutectic lamellæ, as well as the primary crystals of η, are recognisable, without any etching, by their bluish tint. The homogeneity range of the ζ phase has proved to be much narrower than is stated by Kurnakow. In an alloy containing 52·5 per cent. silicon traces of ε were detected; an alloy with 54·9 per cent. silicon showed a fair quantity of very thin η lamellæ. The X-ray photograms, however, show that the composition of this phase also is variable. The lattice parameters vary in the same way, and there is the same degree of probability of a simple substitution as in the case of the ε phase.

If the results of chemical analysis are not falsified by the admixture of silica, the composition corresponding to the formula $FeSi_2$ is out of the range of homogeneity. Yet it seems to the author that the idea "compound" is not stretched too far if the ζ phase is considered as the compound $FeSi_2$, which, however, is not stable unless some of the iron atoms are replaced by silicon atoms.(15)

The lattice parameter of the ζ phase does not show any variation, and hence it seems probable that at ordinary temperatures the amount of iron that is soluble in silicon is negligible.

No reliable determination of the composition of the θ phase has yet been made, because of the difficulty of obtaining this phase homogeneous. If an alloy, containing primary ε and α–ε eutectic, is heated for some hours to 1000° C. the eutectic is decomposed, but the inner parts of the primary ε crystals remain. Yet nothing is found contradicting the conjecture of Murakami, that the composition of this phase corresponds to the formula Fe_3Si_2, *i.e.* 25·1 per cent. of silicon. Quenching experiments have confirmed Murakami's view on the formation of the θ phase at a little above 1000° C. by reaction in the solid state.

The existence of three eutectics is evident from the micro-

graphs. The composition of the α–ε eutectic was found to be 21·2 per cent. of silicon; in it the quantity of ε seems to be considerable (Fig. 9, Plate XXI.). In an alloy containing 20·1 per cent. of silicon no ε is to be seen (Fig. 7, Plate XX.). As a result, the quantity of ε in the eutectic should not exceed one-tenth. This may be taken as an illustration of the difficulty of estimating the relative quantities of the phasés from micrographs.

In spite of this, it may be concluded from Fig. 15 (Plate XXII.) that the composition of the eutectic ε–ζ is not very different from that of the phase ζ. Chemical analysis indicates that the difference is only about 2 per cent. of silicon.

The eutectic ζ–η contains about 61 per cent. of silicon, as primary η crystals can be observed only above this content.

As the phases ε and ζ crystallise from the melt and the crystals are true individuals at ordinary temperature, the existence of an allotropic transformation in any of these phases is very improbable.

Finally, the author wishes to point out that he has never met with a case of metastable equilibrium where the ζ phase did not occur in accordance with the diagram given. Some of the previous investigators [7] have considered metastable equilibria as quite normal where the ζ phase was absent.

SUMMARY.

By means of X-ray and micrographic investigations, the constitutional diagram of the iron-silicon alloys has been modified. In these alloys three intermediary phases occur. Two of them, the composition of which approximately correspond to the formulæ FeSi and $FeSi_2$, have proved to be of variable composition. These two phases and the end phases form three eutectics. The view of Murakami on the formation of the third phase is confirmed. The correctness has been proved of Oberhoffer's hypothesis, that the α-iron and δ-iron areas unite.

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THE TREATMENT OF STEEL WITH FERRO-CARBON-TITANIUM.*

By G. F. COMSTOCK (Niagara Falls, N.Y.).

The object of this paper is to show actually what is being done with ferro-carbon-titanium at the present time, giving an outline of the practical results that are being obtained by its use.

The ferro alloy as used in steel manufacture contains about 17 per cent. titanium and 7·5 per cent. carbon. Pound for pound, it has less deoxidising capacity than the common 50 per cent. ferro-silicon, but in view of the stronger affinity of titanium for oxygen, its use as a final addition, after the silicon and other deoxidisers, results in making the degree of deoxidation of steel more complete.

Ferro-carbon-titanium is essentially a grey cast-iron containing titanium-carbide as well as some dissolved titanium. It is made in an electric arc furnace by reduction of the oxide ore with carbon. A few other types of titanium alloy have a limited practical use, one of the most prominent of them being the alumino-thermic alloy containing about 25 per cent. titanium, partly in the form of nitride, and a considerable amount of aluminium. These other types of alloy are not discussed here as the author is not familiar with their use.

The use of ferro-carbon-titanium as a deoxidiser in the ladle has been found convenient and advantageous at a number of large plants, making good quality effervescing steel for plates and sheet-bar. The amount used generally in this kind of steel varies from 1 to 4 lbs. of alloy per net ton, and depends on the general practice or on the melter's judgment of each individual heat. The advantage of this alloy over aluminium is that it does not make the steel dirty. Steel treated with aluminium can invariably be distinguished by its dirtiness, due to alumina inclusions. On the other hand, aluminium has the advantage that it can be

* Received June 10, 1926.

used in the mould, after the action of the steel in the first mould poured has been observed, while ferro-carbon-titanium must be used in the ladle on account of its slower rate of solution and its carbon content. If insufficient titanium has been added in the ladle, an additional deoxidation can be obtained by using a little aluminium in the moulds.

The use of "silicon pig" in the furnace before tapping is seldom considered a substitute for titanium treatment, but may be practised with the latter. It is not safe to rely entirely upon this method for preventing over-oxidation in effervescing steel, because the proper endpoint of the reaction is not well enough marked. The steel is too often too much deoxidised in this way and the effervescence hindered, unless, as is usually done, the whole effect of the silicon addition is allowed to disappear before tapping. Then the use of titanium in the ladle is advantageous to correct oxidation that may occur after the silicon has all been "worked out." It is sometimes claimed that the use of silicon pig in the furnace "cleans" the steel, but in the tests known to the author where this point has been carefully investigated no effect of this kind was found.

Another advantage from the use of titanium in steel, whether effervescing or not, comes from the fluxing action of its oxide on the furnace slag which may become mixed in the steel.(1) Doubtless the fact that titanium oxide inclusions are not found in titanium-treated steel, as are alumina and silicates in steels treated with aluminium and silicon respectively, is due to this fluxing character of TiO_2.

In the application of titanium to killed steel the conditions are entirely different, and a complete absence of gas evolution as well as the maximum degree of deoxidation are generally desired. Besides manganese, silicon is always used in this kind of steel, generally in the ladle, and in addition aluminium or titanium may also be used in the ladle, or occasionally steel is killed with aluminium in the moulds. This last practice, however, makes very dirty steel and should be discouraged. The amounts of the various deoxidisers used in killed steel differ so greatly, according to the kind of steel made and the general practice followed, that it is impossible in a paper of this scope to give more than a few general observations. The following paragraphs refer to steel

cast into ingots for rolling ; steel for sand-castings will be discussed separately later on.

For steel of low or medium carbon content which is to be killed in the ladle, the usual practice is to use from 5 to 8 lbs. of 50 per cent. ferro-silicon per ton, to give a silicon content of about 0·08 to 0·15 per cent. Under certain conditions, when complete deoxidation is not essential, and a silicon content is to be avoided, about 1 lb. per ton of aluminium may be used in the ladle instead. Ferro-carbon-titanium may be substituted for part of either the silicon or aluminium additions, although its use with aluminium is not generally recommended, because its fluxing action on alumina is not very effective. One pound of aluminium may be considered roughly as the equivalent in deoxidising capacity of about 4 lbs. of 50 per cent. ferro-silicon, or 6 lbs. of ferro-carbon-titanium. This does not mean that titanium is not a stronger deoxidiser than silicon, but merely that it is added in the form of a more dilute alloy. On account of the titanium alloy being of only 17 per cent. strength, it is not practicable to kill a heat of steel with titanium only. It is nearly always used with silicon, in proportions varying from one-half to twice as much as the silicon addition. When used thus it is generally the last addition to the ladle, and tends to clean up the last traces of oxide ; or, in other words, to extend the degree of deoxidation somewhat further than can be attained with silicon alone. In high-carbon steels, as made for rails, titanium is often used in larger quantity, up to 13 lbs. per ton, with a slight decrease in the usual silicon content. This treatment of rail steel has been found to be very effective in controlling segregation in the upper part of the ingot, while merely increasing the usual silicon content has not turned out to be a great success in that direction.

The strong deoxidising power of titanium is described by Dr. Jordan(2) of the Bureau of Standards, who shows that the oxygen content of rail steel decreases from 0·0048 per cent. to nothing as the addition of ferro-carbon-titanium is increased from zero to 10 or 12 lbs. per ton. Further data on the comparative effects of titanium and silicon on rail steel are given by Dr. Burgess and Mr. Quick.(3)

In killed steel ingots in general, titanium is used to decrease segregation by securing more perfect deoxidation, and as has been

already noted, this result is accomplished without the contamination of the steel by any oxidised product analogous to silica or alumina. Finer sulphide inclusions and a less streaky microstructure are also characteristic of titanium-treated killed steel. These effects have been discovered by extensive tests involving the examination of many specimens, and as an example a brief account of a recent test of this kind is given as follows.

Twelve heats of basic open-hearth steel were made at a large steel plant, the compositions ranging between the following limits, as shown by the ladle-test analyses:

	Per Cent.		Per Cent.
Carbon	0·09	to	0·12
Manganese	0·28	,,	0·43
Phosphorus	0·010	,,	0·013
Sulphur	0·020	,,	0·038

The furnaces were charged with about 120 tons of metal, approximately half of which was pig-iron. Different methods of treatment or deoxidation were used, as summarised below, and one or more ingots from about the middle of each heat were chosen for special study. The following kinds of steel were made:

Four heats of titanium-treated effervescing steel, each represented by one ingot.

Four heats of effervescing steel without titanium, each represented by one ingot.

Four ingots of steel, one from each of the above heats, killed in the mould with silicon.

Four ingots of steel, one from each of the same heats, killed in the mould with aluminium.

Two heats of killed steel treated with silicon only, each represented by one ingot.

Two heats of killed steel, treated with titanium and silicon, one represented by two ingots, and the other by one.

No ore was added to these heats less than one hour before tapping except in one instance (untreated, effervescing), and it was interesting to note that the only special ingot that appeared "thin-skinned" at the blooming-mill was from this heat. The slag on each heat was treated with 500 lbs. of burnt

lime about fifteen to forty minutes before tapping, and from three to seven minutes before tapping about 1400 lbs. of ferro-manganese was added to each heat. From about thirty minutes to an hour before tapping each of the killed heats was treated with 1000 lbs. of 15 per cent. silicon pig, and the effect of this addition was allowed to wear off so that the steel boiled freely again. Each class of four effervescing heats was divided into two pairs, one pair being treated with silicon pig in the furnace, and the other pair not so treated. The amount of silicon pig used in the two effervescing titanium-treated heats was 250 lbs. apiece, while in the two effervescing heats without titanium that were treated with silicon pig, 500 lbs. of the latter was used in each.

After tapping, the four untreated effervescing heats received from 20 to 30 lbs. of aluminium in the ladle; and the four treated effervescing heats received additions of 250 lbs. of ferro-carbon-titanium, amounting to from 2·2 to 2·5 lbs. per net ton of steel in the ladle. The killed heats received ladle additions as follows:

Heat.	*J.*	*K.*	*L.*	*M.*
80 per cent. Fe-Mn (lbs.)	25·0	nil	nil	nil
50 per cent. Fe-Si (lbs.)	550·0	550·0	500·0	500·0
,, ,, (lbs. per net ton)	5·3	5·1	4·75	4·4
17 per cent. F.C.T. (lbs.)	nil	nil	400·0	400·0
,, ,, (lbs. per net ton)	nil	nil	3·75	3·35
Total silicon (lbs. per net ton)	2·65	2·55	2·46	2·28
Total titanium ,, ,,	nil	nil	0·64	0·57

The ferro-carbon-titanium was the last addition to the steel in the ladle when it was used, and the ladle additions were all completed before the slag started to flow from the furnace. The first mould was generally teemed from nine to thirteen minutes after tapping, and the 3-ton, 20 in. × 22 in., special ingots were poured usually in about fifty-five or sixty seconds. The titanium-treated effervescing steel ingots sank considerably in the moulds before rimming, but the other effervescing steels which had received a little aluminium in the ladle did not fall or rise very much. 4 lbs. of aluminium, or 11 lbs. of powdered ferro-silicon in the moulds, was found sufficient to kill the ingots. The heats treated

with silicon in the ladle were not completely killed, and the tops of these ingots bulged considerably except in the case of heat *J*.

The special ingots were rolled at one heating down to $1\frac{1}{2}$-inch square billets, and no particular difference was noticed in the rolling character of the different classes of steel, except that perhaps the killed ingots were a little better. An accurate record of the top and bottom discards taken at the mill was kept, and considerable variation, from about 4 to 13 per cent., in individual top discards was noted. There was no consistent difference in this respect, however, between the various kinds of steel. The steel was not followed through the mill beyond the billet stage, and in this test no data on yield or quality of finished product were secured.

Samples for laboratory investigation were obtained from the top, middle, and bottom of each special ingot, in the form of 6-inch lengths of the $1\frac{1}{2}$-inch square billets. Sulphur prints were made only from the top samples of ingots from the killed heats, for previous experience indicated that samples from the lower parts of the ingots would not show anything of interest when tested in this way, and the effervescing steel ingots would, of course, all show segregation at the top. The sulphur prints showed a more uniform distribution of sulphur, in general, in the titanium-treated steel than in the steel treated only with silicon. The discards were sufficiently similar, so that it is not probable that the slight variations had any appreciable effect on the types of sulphur print obtained.

Specimens about $\frac{5}{8}$ inch square were cut lengthwise from near the centre of the section of each billet sample for microscopic examination. After careful polishing each specimen was examined at a magnification of about 180 diameters, and classified in regard to the distribution of the sulphide inclusions, and to the general cleanness or amount of slag and alumina present. The results of this classification were checked by two observers, and afterward the specimens were etched with nitric acid. Another classification was then made, noting the amount of pearlite present, the general grain-size, and the quality of the structure in regard to streakiness.

To facilitate the comparison of the different kinds of steel the notes on cleanness and structure were summarised in the following manner. A grade of "bad" was given the number "0"; a

grade of "poor," 1; "fair" was called 2; and "good," 3. These numbers were then averaged for each class of steel, and the results give a comparative measure of the quality of the different classes in regard to the characteristic under consideration. The notes on sulphide distribution are very similar to those on structure, so that the comparisons on the basis of these two characteristics may be considered as practically the same. A higher number for the average, as given below, means of course a cleaner steel, or a more uniform structure.

	Average Grade in Regard to—	
	Cleanness.	Structure.
Effervescing steel without titanium:	1·00	1·92
With silicon pig in the furnace	0·67	2·33
Without silicon pig in the furnace	1·33	1·50
Titanium-treated effervescing steel:	2·17	1·50
With silicon pig in the furnace	2·17	1·67
Without silicon pig in the furnace	2·17	1·33
Heats killed with silicon in the ladle	1·08	2·13
Heats killed with silicon and titanium in the ladle	1·11	2·77
Steel killed with silicon in the mould	0·33	2·17
Steel killed with aluminium in the mould	0·33	2·33

The titanium-treated effervescing steel was the cleanest of any of these steels, and there was a marked difference in cleanness between it and all the other kinds. The titanium-treated killed steel showed the most uniform structure, as was also indicated by the sulphur prints, but showed only a very slight improvement in cleanness over the other steel killed with silicon in the ladle. The inclusions in the titanium-treated steels were similar to normal silicates, except that they were more apt to show a duplex structure, with a lighter angular constituent embedded in the darker slag. The ingots killed with silicon or aluminium in the mould were very dirty, but showed quite uniform structures. Those treated with aluminium could be very easily identified by the typical alumina inclusions that they contained, in some cases in very large amounts.

The use of silicon pig in the furnace resulted in no improvement in cleanness in the effervescing steels, the only class in which this

comparison was made. The two effervescing heats without titanium that were treated with silicon pig in the furnace showed less pearlite than any of the other heats; this was especially true of one heat, which contained hardly any pearlite at all. Of course where very little pearlite is present, streakiness of structure cannot be very marked, and the high grade of the effervescing steel without titanium, with silicon pig in the furnace, in regard to structure is accounted for in this way, and is probably not directly due to the effect of the silicon pig.

Returning to the discussion of the action of titanium on steel in general, it has been asserted that titanium combines with nitrogen and tends to remove it from the steel. This assertion is undoubtedly justified, and is supported by the fact that distinctive pink crystals of titanium nitride or cyano-nitride are often found in high-carbon steels treated with comparatively large amounts of titanium. As further evidence, some results of nitrogen determinations made on samples of rail steel from different heats and various mills by the modified Allen method are tabulated below:

Nitrogen Content of Rail Steel.

No. of Samples:	Titanium-Treated. 28	Ordinary Steel. 25
	Per Cent.	Per Cent.
Maximum . .	0·0062	0·0100
Minimum . .	0·0015	0·0032
Average . .	0·0036	0·0051

The titanium-treated steel in these heats was treated with 10 to 13 lbs. of ferro-carbon-titanium per ton. In soft steels treated with less titanium, no decreased nitrogen content as compared with untreated steel has been found by analysis. The practical value of the decrease in nitrogen content by titanium treatment as noted above for rail steel is questionable, for the reason that the harmfulness of even more than 0·01 per cent. nitrogen in steel has not been definitely established. Probably there is very little, if any, ferro-carbon-titanium used for the express purpose of controlling the nitrogen in steel, although it undoubtedly does have a slight effect in that direction.

The use of titanium in steel for sand-castings remains to be

considered. This kind of steel must be very thoroughly deoxidised, and is usually made with silicon around 0·3 per cent. Very often aluminium is also used to complete the deoxidation and overcome the last slight traces of unsoundness, but this practice generally results in impaired physical properties on account of the presence of alumina inclusions and streaks of fine sulphides. The aluminium in cast steel causes the sulphides to be finer than usual, and arranged in a network of curved lines which results in early cracking under tensile stress, so that good ductility is not shown.[4] By the use of titanium in place of aluminium as the final deoxidiser, many steel foundries avoid this trouble and secure better ductility in their castings. Titanium treatment of cast steel has also been found practically always to give a better elastic ratio, probably on account of cleaner steel, and a more feathery microstructure as cast, so that grain-refinement by annealing is more easily accomplished and more complete.

In conclusion, it is desired to emphasise the fact that ferro-carbon-titanium is not claimed to be anything wonderful or mysterious. Its value lies in its being a good deoxidiser, more powerful qualitatively than silicon, and one that does not make steel dirty when it is used. In effervescing steel it corrects over-oxidation conveniently, maintaining the cleanness of the metal and not hindering the effervescence. In killed steel it gives more complete deoxidation, without dirtiness, and prevents serious segregation. Like every other alloy, it must be used properly to give good results, and it must not be expected to cure defects which no deoxidiser could overcome.

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(2) L. Jordan: "Gases in Metals," *Proceedings of American Society for Testing Materials*, 1923, vol. xxiii. Part II. p. 19.

(3) G. K. Burgess and G. W. Quick: "A Comparison of the Deoxidation Effects of Titanium and Silicon on Properties of Rail Steel," *U.S. Bureau of Standards*, 1923, Technologic Paper No. 241.

(4) G. F. Comstock: "Aluminium and Titanium as Deoxidisers," *Iron Age*, 1924, vol. cxiv. p. 1477.

CORRESPONDENCE.

Mr. E. Adamson (Sheffield) wrote that the cleansing properties of titanium in blast-furnace practice were well known, and it was natural to find a similar claim made in connection with the Siemens furnace. In perfect effervescent steels the chief object was to throw the gases into the centre of the ingot, where, it was claimed, they were not harmful. That prevented the steel from piping, thereby obtaining a greater yield of bloom from the ingot.

As to yields, on p. 410 the author stated that accurate records of discards at the mill were kept, and there was no consistent difference in that respect between the different kinds of steel, the variations being between 4 and 13 per cent. Did the author mean 4 to 13 per cent. discards from the bloom, or crop-end discards from the ingot? If the former, could he also give even an approximation of the latter, particularly distinguishing between effervescent and killed steels, and before allowing bloom discards at the mill?

When it was stated that in connection with finished products no record was kept, he meant presumably of plates, sections, &c., and he could probably give that information from other sources in connection with both effervescent and killed steels.

On p. 408 the author stated that the only thin-skinned ingot at the blooming-mill was produced from effervescent steel; at the bottom of p. 409 he stated further that titanium-treated effervescent steels sank considerably in the mould. Would he say if that were due to piping, or what form did the sinking take? Comparative data on those points for both effervescent and killed steels with and without the use of titanium would be of the greatest general interest.

The use of ferro-carbon-titanium, as described by the author, certainly raised many possibilities, and if he could give the information asked for it would no doubt considerably help in solving some of the important problems met with in the modern manufacture of steel.

Mr. Comstock replied that he appreciated very much Mr. Adamson's interest in his paper. He regretted that he was unable to reply definitely to each of the questions, but he would give such information as he had on the points raised.

With regard to the gas occurring in blowholes in steel ingots, he believed that it was usually carbon monoxide. If the blowholes were deep-seated and clean, most of them welded up perfectly in working. One of the functions of titanium in such steel was to prevent the contamination of those blowholes with oxide or slag.

He could not separate his data on yields into the four classes mentioned. Imperfectly effervescing steel was not made intentionally

in any of the tests, but some steels did not effervesce as well as others. As a rule, titanium-treated heats were better in that respect, and the yield from imperfectly effervescing steels was not so good. He was afraid he had no figures for thoroughly killed steels such as were made in crucibles or in the basic electric furnace; most of the "killed" steel made on a large scale was not *perfectly* killed. In practically all the tests on that grade, the material was made into rails, and the results were expressed as percentages of defective rails, not as yield of rails from ingots. In American practice with effervescing steel, the yields of slabs or billets from ingots usually amounted to between 80 and 90 per cent., varying considerably at different mills. The titanium treatment generally gave a slightly better yield, because the steel was cleaner, and rolled better. Some representative results were as follows:

	Regular Steel. Per Cent.	Titanium-Treated Steel. Per Cent.
Slabs from ingots	79	83
Plates from slabs	95	97
Sheet bar from ingots	85	88·5
Sheet bar from ingots	92	94
Sheet bar from ingots	69	70·5

In the statement at the bottom of p. 409 he did not refer to the shrinkage that took place in the later stages of solidification. The statement read "sank . . . before rimming," which meant that the level of the steel in the mould sank before solidification of the top began. Rimming steel did not generally pipe very much, but there was always some draw-hole at the centre below the rim. Titanium probably had a tendency to decrease, if anything, the pipe in effervescing steel, but care must be taken not to add enough titanium to interfere too much with the normal effervescence. In killed steel, the addition of titanium increased the pipe, other conditions being constant, because it intensified the killing action, changing the steel from the "partially killed" into the "killed" class.

IS THE DIRECT CHANGE FROM AUSTENITE TO TROOSTITE THEORETICALLY POSSIBLE?[1]

By KÔTARÔ HONDA (Sendai, Japan).

According to the theory of quenching put forward by the present writer[2] six years ago, and now confirmed by the results of X-ray analysis, the Ar1 transformation in carbon steels consists, in its mechanism or process, of two changes—that is :

$$\text{Ar1 transformation} = \text{austenite} \longrightarrow \text{martensite} \longrightarrow \text{pearlite (troostite)}.$$

The correctness of this theory is briefly shown below.

Formerly, as the nature of both austenite and martensite were not very clearly understood, it was not possible to give exact definitions of them ; but thanks to the recent development of the X-ray analysis of metals, knowledge of the nature of these structures is now becoming so exact that they can be defined atomically as follows : Austenite is a structure in which iron atoms have a face-centred cubic lattice with carbon atoms in the interspaces of the lattice ; martensite is a structure in which iron atoms have a body-centred cubic lattice also with carbon atoms in the interspaces of the lattice. These definitions are the same as those generally accepted, that austenite is a solid solution of carbon in γ-iron, and martensite is a solid solution of carbon in α-iron. Troostite, sorbite, and pearlite are each a mechanical mixture of ferrite and cementite ; and hence in what follows the term pearlite will be used for simplicity, whether the structure be troostite, sorbite, or pearlite.

Since the Ar1 transformation is the change of γ-iron into a mixture of α-iron and cementite, this process consists of two changes—(i) the change of the configuration of iron atoms from the face-centred to the body-centred lattice, and (ii) the separation of carbon atoms from the interspaces of the lattice, these

[1] Received May 26, 1926.

[2] *Science Reports of the Tôhoku Imperial University*, 1919, vol. viii. p. 181 ; 1925, vol. xiv. p. 165.

atoms forming cementite by taking up iron atoms when they leave the iron lattice. These two changes being two different processes, it is very difficult to consider them as taking place exactly at the same instant, and hence they will very probably occur in the above order, the second following immediately after the first—that is:

(i) γ-iron dissolving carbon $\longrightarrow$ α-iron dissolving carbon;
(ii) then α-iron dissolving carbon $\longrightarrow$ ferrite + cementite;

or the Ar1 transformation consists of:

γ-iron dissolving carbon $\longrightarrow$ α-iron dissolving carbon
$\longrightarrow$ ferrite + cementite;

that is, austenite $\longrightarrow$ martensite $\longrightarrow$ pearlite.

Thus the correctness of the stepped change is proved.

The formation of martensite by quenching is satisfactorily explained by the above theory of the Ar1 transformation. During a very rapid cooling, such as quenching in water, the change from austenite to martensite is so far retarded that it begins to take place at a temperature below 300° C., and when this change is completed, the specimen which has been subjected to this treatment is nearly at room temperature; hence the second change from martensite to pearlite cannot take place, owing to the great viscosity of the specimen at this temperature. Thus martensite can be obtained by quenching the steel in water.

In the case of an extremely rapid cooling, not only is the second change completely suppressed, but even the first is partially arrested. A martensitic structure mixed with retained austenite is then obtained. In the case of a less rapid cooling than that in the moderate quenching, the first change occurs at a temperature a little higher than in the latter case; hence not only does the first change take place, but the second change does so also, but only partially, resulting in a martensite mixed with troostite. As the cooling rate becomes less, the second change takes place more and more completely, the troostite area increasing at the expense of the martensite.

In the case of the formation of troostite by quenching as referred to above, or if a steel be quenched during the progress of the Ar1 transformation, it is found that troostite develops in a granular form from the boundary of austenite (Fig. 1, Plate XXIV.). Such a troostite is usually said to be directly produced from

FIG. 1.—Granular troostite (Lucas).

[To face p. 418

austenite; but this is not the case. For, when the change from austenite to martensite takes place at a low temperature, say below 300° C., the change proceeds slowly, and iron atoms which change their configuration from the γ-type to the α-type, the carbon atoms still remaining in the interspaces of the lattice, have sufficient time to build up the characteristic needle-shaped crystals. But if the change takes place at a relatively high temperature its progress is very rapid, and hence, as soon as the iron atoms change their configuration from the γ- to the α-type, the precipitation of cementite takes place. In this case there is not sufficient time for the formation of the needle-shaped crystals, and granular troostite is formed from the nuclei as centres on the grain boundary of the austenite.

Here it is to be remarked that, though the crystal form is not needle-shaped, α-iron containing carbon as a solid solution may safely be called martensite. The external form of a crystal may change according to the different conditions to which it is subjected during its formation. For example, according to X-ray analyses made by Osawa,[1] limestone, marble, coral, oyster-shells, crab-shell, fowl's eggs, &c., have all the same space-lattice as calcite, though they differ from each other so much in appearance; their true nature is therefore the same as that of calcite.

From what has been explained above, it is to be concluded that, as the change from austenite to troostite necessarily involves two changes, consisting of the change in atomic configuration and of the precipitation of cementite, any change from austenite to troostite must take place through martensite. Hence such a phrase as "direct change from austenite to troostite" has no meaning, unless by it is meant that the martensite, which is formed from austenite, is *immediately* changed into troostite. It is therefore to be concluded that troostite is invariably the decomposition product of martensite, and not a product directly decomposed from austenite.

In connection with the nature of martensite, a remark on the well-known question whether the carbon in martensite dissolves in α-iron as carbon atoms or as cementite molecules is not out of place. Some metallurgists consider martensite to be a solid solution of cementite in α-iron, because by the decomposition

[1] *Journal of the Iron and Steel Institute*, 1926, No. I. p. 447.

of martensite, cementite, but not graphite, is always produced. This reasoning is, however, not correct, for, assuming an atomic dispersion of carbon, during the Ar1 transformation the carbon atoms in the interspaces of the lattice can move towards the grain boundaries, and on leaving the α-iron each will take up three iron atoms to form a cementite molecule and separate as such.

As already remarked, the iron atoms in martensite have a body-centred cubic lattice, while carbon atoms are present in the interspaces of the lattice. Their actual position is not yet known, but, theoretically considered, these atoms cannot approach too near to the iron atoms on account of the repulsive force which comes into play between the two kinds of atoms when they approach very near together; also they must occupy a symmetrical position in relation to the iron atoms. So in order to satisfy these two conditions, the carbon atoms in martensite will either occupy positions in the centre of the face of an elementary cube, or near the middle point in the cube diagonal between the corner and the centre, being distributed here and there according to the law of probability. Assuming for carbon atoms these two positions, or any other conceivable positions within the space-lattice, any groups of iron and carbon atoms out of the given configuration just referred to, yet which would correspond to the molecule Fe_3C, cannot be imagined. Groups or molecules such as Fe_6C and Fe_4C, corresponding to the two positions just referred to, may be conceivable, if desired; but such a conception has no importance. A similar remark applies also to the case of austenite.

Thus, accepting the atomic dispersion of carbon in both α- and γ-iron, it is terminologically more correct to say that the carbon in austenite and martensite dissolves in iron as carbon atoms, but not as cementite molecules.

CORRESPONDENCE.

Mr. A. Hultgren (Söderfors, Sweden) wrote that he saw no difficulty in conceiving that the two changes involved in the transformation of austenite into pearlite took place exactly at the same instant, and he would try to make his views clear by first referring to the separation of free ferrite and free cementite respectively.

When, on slow cooling, free ferrite separated from a low-carbon austenite at isolated centres, a few iron atoms first re-grouped themselves into a body-centred lattice. The carbon atoms in solution in the austenite at those centres, since they were not admitted to the new lattice, would to some extent accumulate about the new ferrite units. Thus the growth of the latter would be governed, apart from the rate of cooling, by the rate of diffusion of the accumulated carbon atoms into such parts of the austenite where no ferrite nuclei had yet formed.

In a high-carbon austenite the separation of free cementite presented an analogous picture. The new individuals were then formed by iron and carbon atoms in the proportion of 3 to 1. The surrounding austenite being, in consequence, to some extent impoverished in carbon, received a continuous supply of carbon atoms by diffusion, and thus the growth of the cementite nuclei was rendered possible.

Pearlite, on the other hand, was formed as a result of the austenite being undercooled below the ferrite as well as the cementite separation line. The formation of pearlite, therefore, should be regarded as the simultaneous separation of ferrite and cementite, made possible by the diffusion through the adjacent austenite of carbon atoms rejected from the advancing front of each ferrite lamella to the fronts of the two cementite lamellæ adjoining it. Troostite, in the form of *rounded grains*, as seen in hardened carbon steel, was essentially identical with pearlite, only finer, owing to the increased undercooling and diminished power of diffusion of the carbon atoms. If the above view were correct, it was justifiable to speak of "the direct change of austenite to troostite," and, contrary to the author's opinion, there was no need for postulating a so-called stepped transformation.

On the other hand, *needles* of troostite sometimes occurred in hardened carbon steel and, more frequently, in alloy steels. In that case he (Mr. Hultgren) believed martensite needles had first formed and had then been tempered, this being due to temporary retardation in the cooling, or, particularly in alloy steels, to the comparatively slow cooling rate generally employed in quenching such steels. The term "stepped transformation" would then be applicable.

If the author's view were correct, it would logically follow that any constituent separated from a solid solution—for instance, cementite from austenite—would, as first formed, have the same composition as the mother solution, in spite of the lattice being changed. It would be of interest to know whether the author accepted that conclusion.

The AUTHOR, in reply, thanked Mr. Hultgren for his communication. He thought that Mr. Hultgren's views on the transformation of austenite to pearlite, if he understood him correctly, did not differ in the least from his own. With regard to Mr. Hultgren's explanation of the slow cooling of a hypo-eutectoid steel, it must be pointed out that his *ferrite*, as first formed, still contained carbon atoms in the interspaces of the lattice, and hence was not ordinary ferrite ; it was really martensite, as defined in the paper. Thus Mr. Hultgren's views on the separation of ferrite from austenite meant that the first change was in reality the change from austenite to martensite, and the second was the rejection of carbon atoms from the martensite to form *pure ferrite.*

In the case of a hyper-eutectoid steel, the separation of cementite from austenite on the solubility line, where the allotropic transformation A3 was accomplished, was somewhat different from that of ferrite. During the cooling of the austenitic steel across the solubility line, carbon atoms began to be set free as cementite molecules, and to form the characteristic cementite lattice, but no lattice change occurred in the austenite until the A1 point was reached. That would also answer Mr. Hultgren's question in the last part of his discussion.

He, like Mr. Hultgren, regarded the formation of pearlite at the A1 point as the simultaneous separation of ferrite and cementite by mechanism similar to that described above. At the A1 point an isolated microscopic portion of austenite might be supposed to undergo a lattice change to the α-type—martensite—and carbon atoms, inadmissible to the latter lattice-form would be rejected, and form cementite molecules. Those molecules would accumulate by diffusion, so forming separate masses of ferrite and cementite. In the next instant an adjacent portion of the material would undergo the same change, and the repetition of that series of transformations would give rise to the formation of lamellar pearlite. That way of regarding the A1 transformation seemed to be the same as that of Mr. Hultgren.

In the above processes, the first change—the lattice change from γ to α—was in reality the change from austenite to martensite, and the second change—the rejection of carbon atoms from the α-lattice—was the change from martensite to pearlite ; that is, the mechanism of the A1 transformation was : austenite $\rightarrow$ martensite $\rightarrow$ pearlite. It seemed to him (the author) that Mr. Hultgren tacitly admitted the two changes taking place one after the other.

VISITS AND EXCURSIONS AT THE STOCKHOLM MEETING.

For the purpose of making the arrangements for the Stockholm Meeting, an influential local Reception Committee was formed by Jernkontoret. The President of the Committee was Mr. Jonas C. Kjellberg, Hon. M.I.S.I. President of Jernkontoret and Chairman of the Uddeholm Company. The Committee consisted besides of the following noblemen and gentlemen :—Emil Kinander, Managing Director of Jernkontoret, Chairman, Boxholm Works and A.B. Svenska Handelsbanken ; Count Gösta von Rosen, Member of the Board, Jernkontoret, Member of the Board, Fagersta Steelworks ; Baron Herman Fleming, Member of the Board, Jernkontoret ; Arvid Sjögren, M.I.S.I., Member of the Board, Jernkontoret, Managing Director, Forsbacka Steelworks ; Aug. Herlenius, M.I.S.I., Member of the Board, Jernkontoret, First Gentleman of the Bed Chamber to H.M. the King, Managing Director, Uddeholms A.B. ; Baron C. J. Beck-Friis, Member of the Board, Jernkontoret, owner of the Harg Ironworks (Dannemora) ; Carl Sahlin, M.I.S.I., Member of the Board, Jernkontoret ; Tord Magnuson, Member of the Board, Jernkontoret, Chairman, Sandviken Steelworks ; Emil Lundquist, Member of the Board, Jernkontoret, Managing Director, Stora Kopparbergs Bergslags, A.B. ; His Excellency Sir Arthur Grant Duff, K.C.M.G., British Minister Plenipotentiary in Stockholm ; Joh. Ax. Almquist, Ph.D., Councillor of the Royal Court of Record ; Rear-Admiral Sten Ankarcrona,

M.I.S.I.; A. Gerh. Arfwedson, Managing Director, Ulfshytte Ironworks; Professor Carl Benedicks, Ph.D., Hon. Vice-President, Iron and Steel Institute, Director, Metallographic Institute; Axel Carlander, Chairman, Chamber of Commerce, Gothenburg, Chairman of A.B. Svenska Kullagerfabriken (S.K.F.); Allan Cederborg, President of Stockholm City Council; Baron Gerard de Geer, Managing Director, Kloster Steelworks; G. Dickson, Chairman, Anglo-Swedish Society, Gothenburg, and Aktiebolaget Göteborgs Bank; Gunnar Dillner, M.I.S.I., President, Swedish Industrial Association, Managing Director, Grängesberg and Luossavaara-Kiirunavaara Companies; Harry von Eckermann, Ph.D., M.I.S.I., Managing Director, Ljusne Works; J. S. Edström, Chairman, Surahammar Works, Managing Director, Allmänna Svenska Elektriska Aktiebolaget (A.S.E.A.); Gust. Ekman, M.I.S.I., Managing Director, A.B. Göteborgs Bank, Member of the Board of Uddeholms A.B.; Professor Axel F. Enström, Director, Academy of Engineering Sciences; Axel Fornander, M.I.S.I., Managing Director, Fagersta Steelworks; K. A. Fryxell, Director-General, Swedish Board of Trade; Axel Granholm, Director-General, Swedish State Railways; K. F. Göransson, M.I.S.I., Managing Director, Sandviken Steelworks; G. K. Hamfeldt, Managing Director, Oxelösunds Works; F. V. Hansen, Director-General, Royal Board of Waterfalls; C. F. W. Hederstierna, Member of Riksdag, Governor-General of Stockholm, late Minister of Foreign Affairs; Olof Hjorth, M.I.S.I., Managing Director, Hofors Steelworks; H. Th. Holm, Managing Director, Bofors Works; Kristoffer Huldt, M.I.S.I., Chairman, Kohlswa Works, President of the Swedish Association of Engineers and Architects; Gustaf Jansson, M.I.S.I., Manager, Munkfors Steelworks; Axel A. Johnson, M.I.S.I., Consul-General, Chairman, Avesta Works; Wiking Johnsson, Director, A.B. Svenska Handelsbanken, Member of the Board, Gimo-Österby Works; His Excellency H. L. F. Lagercrantz, Envoy and late Minister Plenipotentiary in Washington, President, Swedish Export Association, Chairman, Gimo-Österby Works; L. U. Lindberg, M.I.S.I., Chairman, Fagersta Steelworks; Rear-Admiral Arvid Lindman, G.C.V.O., M.I.S.I., Member of Riksdag, late Prime Minister, Chairman, Strömbacka Works; Sven Lübeck, Governor of the Province of Gävle, President of Academy of Engineering

Sciences; Baron Johan Nordenfalk, First Gentleman of the Bed Chamber to H.M. the King; Ernst Odelberg, M.I.S.I., Managing Director, Strömsnäs Steelworks; Professor Walfr. Petersson, Ph.D., Dean of the Royal College of Mining and Metallurgy; Walter Philipson, Chairman, Grängesberg and Luossavaara-Kiirunavaara Companies, Director, Swedish State Bank; Professor H. B. M. Pleijel, Ph.D., Rector of the Royal Technical College; Bj. Prytz, Managing Director, Svenska Kullagerfabriken (S.K.F.); Carl Swartz, D.C.L., Member of Riksdag, Chancellor of the Universities, late Prime Minister, Chairman, Skandinaviska Kreditaktiebolaget; Olof Söderberg, M.I.S.I., Consul-General; His Excellency E. B. Trolle, G.C.V.O., Governor of the Province Ostergötland, Chairman, Motala Works, late Minister of Foreign Affairs; Ernst Trygger, D.C.L., Member of Riksdag, Chairman, Iggesund Works, late Prime Minister; Count Henning Wachtmeister, Lord-in-Waiting, Member of the Board, Stora Kopparbergs Bergslags Aktiebolag; Axel Wahlberg, M.I.S.I., Chief Metallurgist of Jernkontoret, Chairman, State Testing Department; K. A. Wallenberg, Chairman, Chamber of Commerce, and Stora Kopparbergs Bergslags A.B., late Minister of Foreign Affairs; Marcus Wallenberg, President, Swedish Bank Association, and Vice-Chairman, Stora Kopparbergs Bergslags A.B.; E. Wettergren, M.I.S.I., Managing Director, Boxholm Works; Th. Wigelius, M.I.S.I., Managing Director, Hellefors Works.

For carrying out the details of the work a small executive committee was chosen from the above-named members of the Reception Committee, consisting of Mr. E. Kinander, Managing Director of Jernkontoret, as Chairman, Count Gösta von Rosen, Mr. Axel Wahlberg, Mr. August Herlenius, Mr. Thorsten Wigelius, with Mr. Alf Grabe as Hon. Secretary.

In addition, a Ladies' Reception Committee was formed, consisting of the following—Mrs. Kinander, Mrs. Herlenius, Mrs. Wahlberg, Mrs. Wigelius, Mrs. Grabe, and Miss Carlander. Throughout the time of the meeting, and also during the three days while the members were absent on excursions to works, these ladies devoted themselves unremittingly to making the stay of the lady visitors as agreeable and pleasant as possible.

His Excellency Sir Arthur Grant Duff, K.C.M.G., British Minister Plenipotentiary in Stockholm, and Lady Grant Duff,

manifested a very warm interest in the proceedings throughout the days of the Meeting. On Thursday, August 26, they invited Sir Peter Rylands the President, Sir Hugh Bell, Bt., C.B., and the other Members of Council in Stockholm, Sir William Larke, K.B.E., Director of the National Federation of Iron and Steel Manufacturers, and the Members of the Stockholm Reception Committee, to luncheon at the British Legation. The guests also included Mr. H. Kershaw, Commercial Secretary to the British Legation. The Minister was good enough to honour the President, Council and Members by attending the General Meetings of the Institute at the Palace of the Nobility on the following days, and with Lady Grant Duff he was present at all the social events of the week which had been arranged in connection with the Meeting. Thanks are also due to Mr. Kershaw, the Commercial Secretary, and Mrs. Kershaw, for their kind interest and helpfulness in entertaining the Members and their ladies.

A silver badge of membership was designed by the Committee, an illustration of which appears at the head of this report. The device in the centre encircled by a chain from which a casket is suspended is taken from the ancient seal of Jernkontoret.

The formal proceedings opened on Thursday evening, August 26, with a conversazione and reception at the House of Jernkontoret, the rooms of which had been beautifully decorated for the occasion with flowers, palms, and flags. The guests were received by Mr. Jonas C. Kjellberg, President of Jernkontoret, and Mrs. Kinander, and the halls presented a brilliant scene, being thronged with members with their ladies, their hosts, and a large gathering of distinguished citizens of Stockholm. Among the guests were also Sir Arthur Grant Duff, K.C.M.G., H.M. Minister Plenipotentiary in Stockholm, Lady Grant Duff, and Mr. Kershaw, Commercial Secretary to the British Legation, with Mrs. Kershaw. Several Ministers and Ex-Ministers of the Swedish Crown were likewise present. The proceedings continued to a late hour, concluding with a dance.

On August 27 the General Meeting opened in the Palace of the Nobility, where Mr. Kjellberg, in a short speech, extended a cordial welcome to the visitors on behalf of Jernkontoret. Mr. K. Huldt, President of the Swedish Society of Civil Engineers and Architects,

associated himself with Mr. Kjellberg in welcoming the members. The President, Sir Peter Rylands, replied suitably, and announced to the meeting that the Council had unanimously elected Mr. Kjellberg an Honorary Member of the Institute that morning. The proceedings then continued in their usual form, and the meeting was adjourned at 12.45 P.M. By arrangement of the Swedish Society of Civil Engineers and Architects, automobiles were in waiting to conduct the members and ladies for a drive through the city, the route including a circuit through Staden, the old part of the city, to Hasselbacken.

Lunch at Hasselbacken.—About 1.30 P.M. the whole party were entertained at lunch at Hasselbacken by the Swedish Society of Civil Engineers and Architects, Mr. Huldt, the President, occupying the Chair. Mr. Huldt, after lunch, proposed the health of the guests, bidding them welcome in the name of his Society. That Society, he said, was the modern representative body of the engineering craft of Sweden, which was of very ancient origin, the Swedish race having been renowned for its technical skill since prehistoric times. Sir Peter Rylands, the President of the Institute, having suitably replied, Mr. K. A. Fröman, the Secretary of the Society, to whom thanks are due for the manner in which he planned all the arrangements, announced the further programme for the afternoon.

The drive about the city was resumed in company with Mr. Huldt and members of the Swedish Society, who courteously acted as guides. Professor R. Östberg, the celebrated architect of the new City Hall, accompanied the party, which eventually reached the City Hall, where they alighted. In the courtyard Professor Östberg, speaking in English from the steps of the great entrance to the Blue Hall, gave a short descriptive account of the manner in which the work had been carried out, and drew attention to the chief architectural features of the building and its situation. The visitors then again betook themselves to their automobiles, and the party divided into two, one group going to the Ericsson telephone works, where they were courteously received and shown over the factory. The other group was taken to the Royal Palace, where, under the expert and learned guidance of Dr. Böttiger, Director of the Palace, they spent the remainder of the afternoon in visiting the State apart-

ments and other rooms not usually open. The visitors passed a delightful two hours in listening to the interesting explanations of Dr. Böttiger, and his descriptions and stories concerning the many wonderful and unique objects of art displayed in the various rooms.

Banquet at the Grand Hotel Royal.

On Friday evening, August 27, the members and their ladies were entertained at a banquet at the Grand Hotel Royal by invitation of Jernkontoret. Mr. J. C. Kjellberg, President of Jernkontoret, presided over a large and brilliant gathering, which included His Excellency E. Trygger, Ex-Premier of Sweden ; His Excellency E. Löfgren, Minister of Foreign Affairs, and other Ministers of the Swedish Crown ; Baron Palmstierna, Swedish Minister Plenipotentiary in London ; Sir Arthur Grant Duff, K.C.M.G., His Majesty's Minister Plenipotentiary at Stockholm, and many other distinguished personages. The Toasts of His Majesty the King of Sweden, His Britannic Majesty, and the Heads of other States represented at the Dinner were proposed in Swedish fashion and were duly honoured.

His Excellency E. Trygger (Ex-Prime Minister of Sweden) then gave the Toast of Great Britain. He said that it was common knowledge that there was an Empire upon which the sun never set, and they would show but little interest in what history could teach if they did not attempt to penetrate into the secrets of how such a power could be created. Ancient Albion, which Cæsar castigated in order to safeguard his conquest of Gaul, had, through changing fortunes, developed to the equal of the Roman Empire, and now gave to millions of people safety and security which had as its model the famous *pax Romana*.

Without wishing to minimise the importance of the geographical position of Great Britain and its natural resources as underlying causes of that magnificent development, it had to be recognised that it was the nation itself and its qualities which had been the determining factors of that gigantic creation. Opinions might differ in regard to the question whether a purer race would form a more vital nation than would a mixture of kindred races, but surely the British nation afforded splendid evidence of the fact

that the latter way could lead to the greatest perfection. To arrive at that perfection, the first condition was that a nation should be saturated with a belief in its own power to achieve great deeds, and in looking back on the history of England it was found that the great period of the country began when such a belief prevailed. A single effort, however, was not enough, and history showed that an impulse of that kind could gradually die down in a nation, and its development, as a consequence, be led into more modest paths. The idea of greatness had to be retained through good and ill, the sacrifices which the situation in each case demanded having to be made, however heavy they might be. In that respect he thought the British nation was still holding the same position as did the Roman Empire during the foremost period of its existence. They all knew that the greatness of a nation was not built up merely by high ideas of itself and of its historical mission; readiness for sacrifice, strength and wisdom, were factors also necessary to carry out the scheme. It could not be denied that, to an outsider, the strength of a nation sometimes suggested that there was a lack of consideration to others and a tendency to seek and derive profit from their follies and mistakes. It seemed almost impossible to decide where the right line of demarcation should be drawn, but it was undeniable that what had to be done to build up and maintain a world-empire, and what was the right way to direct a purely national state, were very different matters. In the latter, principles could be more rigidly adhered to and methods could be more uniform, but within a world-empire there was greater need for a spirit of accommodation and compromise, and circumstances had to be taken into consideration, even if it necessitated a modification of leading principles. He thought that British policy, as far as he could understand it, was governed by that view, which he ventured to suggest was the foundation of the wonderful successes of British foreign policy and of the admirable achievements of the British nation in connection with industry, commerce, shipping, and finance.

He had suggested only some of the qualities which he thought had helped to build up the British Empire, but there was something more in that great nation which had enabled it to play its great part in history. He referred to its love of liberty, spiritual and civic, its veneration for tradition, its social virtues, its

clear perception of realities, and last, but not least, its ardent patriotism.

In conclusion, he said that he felt it a great honour to be allowed on that important occasion to propose the health of Great Britain, and he drank to her happiness and her great future.

Sir W. Peter Rylands (President of the Iron and Steel Institute) thanked His Excellency for the cordial manner in which the Toast had been proposed, and those present for the hearty way in which it had been received. British people liked to hear nice things said about themselves. Swedes and Britons had buried their differences, and had been linked together as friends in the bond of peace for many hundreds of years. Centuries ago, however, he believed that representatives of the Swedish race successfully raided the English shores and returned laden with spoil. In a similar manner, in the peaceful realms of commerce Swedish business men now visited England for the purpose of doing business in their very excellent iron and steel, and went back to their country laden with their spoil, as their forefathers did. He hoped that the spirit of friendly rivalry which had existed between Sweden and Great Britain would continue for many years to come.

Mr. J. C. Kjellberg (President of Jernkontoret) next proposed the Toast of the Iron and Steel Institute. He said: This morning I had the opportunity of telling you, Mr. President, and Members of the Iron and Steel Institute, how glad and proud we are to welcome you to Stockholm. There are many links between your Institute and our own, the Jernkontor—sister societies we may call them—although the Jernkontor, having existed since 1747, the difference in age of over 120 years is somewhat unusual in the case of sisters. Many Swedish ironmasters and metallurgists have joined your Institute as members, and three of our countrymen—Åkerman, Gjers, and Brinell—have been honoured by the award of the Bessemer Medal, this high distinction being proof of your recognition that Sweden too has produced men who have mightily distinguished themselves as metallurgists. Your presence among us this year again, as upon a previous occasion, for the purpose of meeting and of visiting some of our works, also proves that you consider we have something of interest for you to see. But in the course

of your visits you must bear in mind that these works are comparatively small, although not so small as at the time of the foundation of the Jernkontor, when the number of works in Sweden producing wrought iron was about 450, giving an output larger than any other country, and twice as large as that of Great Britain at the same period. It will afford us very great satisfaction if after completion of your tour you find that you have been ever so slightly rewarded for your long journey. Whatever we can do for you we shall still be your debtors for all that we have learned from your country—for instance, the Lancashire method, which formerly was of very high importance for us, and the Bessemer process. Further, we shall never forget what we owe to you for your Journal, that valuable work of reference on the metallurgy of iron and steel, which forms a standard work for metallurgists in all countries. I feel sure that nothing will benefit the progress of our industry more than for metallurgists all over the world to compare their experiences and exchange ideas. No country alone is able to make all the necessary researches and experiments, and we must stand together, and reveal to each other the results we obtain.

Before concluding these words I may add that we are delighted to see among our honoured guests the Grand Old Man of the Institute, Sir Hugh Bell, Past-President, and a member of the Institute since its foundation nearly sixty years ago. We know well the high position that Sir Hugh Bell holds in his country, and his name with that of his father, Sir Lowthian Bell, is always regarded by us with the deepest reverence. We who have been fortunate to be pupils of his friend, Richard Åkerman, will never forget how often Åkerman referred to Sir Lowthian Bell's researches. Finally, I beg again most respectfully to thank you, Mr. President and the Council, for the great distinction conferred upon me in electing me an Honorary Member, which I consider to be a token of regard for the Jernkontor, and one which will be highly appreciated by its members. I ask the guests and the members of the Reception Committee to join with me in a Toast to the prosperity of the Iron and Steel Institute.

Sir Peter Rylands (President of the Iron and Steel Institute), in responding, first of all thanked Jernkontoret for the magnificent

hospitality they had showered upon the members, which they would never forget. It was very gratifying to them to receive once more an invitation from Jernkontoret to come to Sweden and see that fruitful country and the progress that had been made in the great industry in which they were all interested. In coming to Sweden they were visiting the nursery of the iron and steel industry, which took its rise within that country. During the past two thousand years Sweden had regarded the production of iron as one of her most important interests, and he believed during the whole of that period, certainly during later times, its kings and the great men of the land had taken a great interest in furthering its prosperity. During the last two hundred years, with which they were more concerned, Sweden had set an example to the other iron and steel-making nations of the world, particularly to Great Britain, in the great organisation over which the Chairman had the honour to preside—an organisation made possible by the far-seeing men of two hundred years ago by whom it was founded.

During the morning session the members had heard, when Mr. Kinander read his paper, an inspired story of the history of that great organisation. Reference was made to many names, but there was one which made a special appeal to him, and probably to many of the members present, namely, that of Reinhold Angerstein. He wondered how many of the members took the opportunity, during the Reception at Jernkontoret on the previous evening, to examine the wonderful books written out by Reinhold Angerstein in his own hand, telling the story of the production of iron 160 years ago. It consisted of seven volumes of closely written manuscript, showing a close attention and love for the task which must be an inspiration to metallurgists of the present time. He did not wonder that Jernkontoret considered those manuscript books one of their most treasured possessions. The members of the Iron and Steel Institute regarded it as unfortunate that Jernkontoret had not yet seen its way to publish it, so that they might have an opportunity of perusing what must be a remarkably interesting record of the times in which Reinhold Angerstein had lived.

During the past two hundred years, under the guidance and the stimulating courage of Jernkontoret, great strides had been made on the technical side of the industry in Sweden. He

need not refer to the many names that were enrolled upon their banners. Brinell was one of whom any nation might be proud. He was sure Jernkontoret was proud to carry on the great tradition which lay behind them, and, having regard to the long period through which Jernkontoret had been carried on with success, he had no doubt it might look forward to a useful future for many years to come. British metallurgists viewed their achievements with a feeling of intense admiration and perhaps, it might be, with a little envy. Unfortunately, it was not their experience in Great Britain that associations among manufacturers were very long-lived. He had been connected with some which had lasted twenty-five years, and that was regarded as a very great age for an industrial organisation in Great Britain. He looked forward to a greater realisation of the benefits which might be derived from co-operative effort, by following the wonderful example which had been set before them by Sweden, the metallurgists of which country had worked so harmoniously together for many years. He again expressed his great appreciation of the splendid reception which had been accorded to the members, and for a hospitality not offered in a perfunctory sort of way, but a hospitality which came from the heart, with a real desire to extend the friendly feeling which existed between the peoples of the two nations.

The Toast of " The Ladies " was then proposed in an exceedingly witty speech by Mr. Thorsten Wigelius, Managing Director of Hellefors Ironworks.

Sir Hugh Bell, Bart., C.B. (Past-President), who was called upon to speak, said it was difficult for him to know the exact position in which he stood. The President of the Institute had already offered the sincere thanks of the members for the quite extraordinary hospitality their hosts had been good enough to extend to them, and it seemed to him that the reply might very well rest there. He came to the conclusion that there was only one ground on which he could base any right to address the gathering—a ground which all those present ran the risk of reaching sooner or later if they only lived long enough. He could not help being born in 1844, so that he was left no alternative but to be 82½ years old,

which seemed to be extremely insufficient ground to warrant his taking up the time of the meeting. It was therefore necessary for him to find some other justification for making a speech, and two thoughts occurred to him. The first was to follow the suggestion made by the President as to whether they were altogether on the right lines in their relations with one another. Commerce was not conflict; it was co-operation. He was one of those who were firmly persuaded that unless a man bought neither could he sell, and, what was still more to the point, that no bargain was a good bargain which was not beneficial to both parties concerned. He did not like to feel that the other man had made no profit; on the other hand, he did not like to think that he had made more than his just share. He had endeavoured during the sixty-four years in which he had been engaged in the iron trade to get across the bridge without falling into the water, either on the one side or the other. The other thought that occurred to him was that in England, when the health of the ladies was proposed, it was usual to invite the youngest man in the company to respond. He was going to make the claim of being the youngest man present, since he was entering his second childhood, and, with the permission of the ladies, he therefore responded on their behalf. In doing so he thanked the ladies for their presence and for the pleasure it had given.

Mr. Emil Kinander (Director of Jernkontoret) then proposed the Toast of the Guests. He said: My friend Mr. Kjellberg has toasted the Iron and Steel Institute, but besides the members of that Society we have the pleasure to welcome here to-night a large number of other distinguished guests to whom it is my agreeable duty to propose another Toast. Before proceeding, however, I have first to express our deepest regret that Lady Grant Duff, owing to a sudden indisposition, is prevented from being with us this evening, and we beg His Excellency Sir Arthur Grant Duff to transmit to her our best wishes for her early recovery.

Since the days of its foundation, Jernkontoret has always maintained most friendly relations with kindred Institutions with which it has been brought in contact or with which it has collaborated in promoting its objects. His Majesty's Ministers have been ever ready to give sympathetic consideration to proposals made by

Jernkontoret, as representative of the Swedish iron trade, whenever it has felt it incumbent to submit its opinion on questions affecting the interests of the industry in general. It has of course happened, and perhaps must happen, that those questions have not always been settled in accordance with Jernkontoret's own judgment; but there has never been a break in our good relations, and it is a great pleasure to us to express our thanks to those of His Majesty's Ministers who have honoured us with their presence: His Excellency E. Löfgren, Minister for Foreign Affairs, and the Minister for Communications and for Commerce; also, to the official representative of Great Britain, Sir Arthur Grant Duff, and the present staff of the British Legation, and to His Excellency Baron Palmstierna, our Minister Plenipotentiary in London, we wish to express our sincere thanks for their kindness in honouring this banquet by their presence. I also desire especially to thank the First Marshal to His Majesty our King for his great kindness. We are very delighted to welcome among us the representatives of a number of State and private Institutions with whom Jernkontoret has collaborated, and from whom we have received unfailing support and appreciation. If I may venture to refer specially to any of these Institutions I must first mention the Board of State Railways, which, as on numerous previous occasions, has again granted facilities by arranging, in co-operation with private railway companies—to whom our sincere thanks are also due—the excursion trains that are to carry our British guests to some of the iron-making and mining districts.

We are also grateful to Svenska Teknologföreningen, which has assisted Jernkontoret in acting as hosts to the members of the Institute; to the Royal Technical University, and more especially to the Royal School of Mining and Metallurgy; the Government Testing Institute and the Metallographic Institute. We thank them all for their valuable help. We also extend special thanks to the City of Stockholm for their hospitable invitation to dine in the City Hall to-morrow; further, to the owners of the Gustavsberg Porcelain Factory for their kind invitation to Gustavsberg and the surroundings; and to the representatives of the Press, foreign as well as Swedish. We have to express our indebtedness for the kind attention which has been bestowed upon this meeting so important to us.

Finally, I wish to direct our heartiest thanks to Jernkontoret's own collaborators on the economic as well as on the technical side. I refer especially to those who by valuable papers have contributed to making known Jernkontoret's position in the field of metallurgical science. I am aware that there are a large number of institutions and individuals to whom our cordial thanks are likewise due, but it is scarcely possible within the time at my disposal to refer to them all by name, and I can only conclude with the assurance that their presence is most welcome to us, and we desire to offer an expression of our gratitude to all whether named or not named, not only for their kind assistance in making the visit of our sister Institute to Sweden as pleasant and agreeable as possible, but for old friendship's sake. I beg you all to join in a Toast to the guests in the Swedish fashion.

Mr. H. Kershaw, Commercial Secretary to the British Legation at Stockholm, in responding, said that Sir Arthur Grant Duff thanked Mr. Kinander very much for his kind references, and as Sir Arthur's name had been coupled with that of Baron Palmstierna, he had requested him to say how pleased all the British representatives were at the presence in their midst of the Swedish Minister and the Swedish Consul-General in London, who had done, and were doing, so much to develop the excellent relations, both political and economic, which had always existed between the two countries.

Sweden had always excelled in any industry which she had taken up. Her products during the Neolithic Age were amongst the wonders of the world, the most beautiful and efficient stone axes which were to be found in any country having been made there. During the unhappy interlude of the Bronze Age, the only epoch during which Sweden had been compelled to rely on foreign production, they might at any rate hope that the kings of the Suiones had derived a good income from the imported bronze articles, which must have been an eyesore to makers of fine stone weapons. When the Iron Age began and it was found that the ironstone of the marshes could be utilised, a new era opened which had never since been interrupted, and from lowly beginnings the iron and subsequently the steel industry attained to its present state of perfection.

While Sweden had reached such a pitch of prosperity in so many industries, and in metallurgy above all, she had always kept in close touch with Nature. The forest was never far distant, and even in the immediate proximity of mines, metal works, or factories, equipped with every modern device, it was possible to find oneself in the wilderness—the *ödemark,* as they said in Swedish; and when one was oppressed by the problems and perplexities of the modern world, there was nothing like a short time in the wilderness, or the forest, for obtaining relief from the cares of business. The balance between modern industry and Nature had been brought to perfection in that country, and they hoped that that happy state of things would always continue.

Mr. E. Löfgren, Minister for Foreign Affairs, also responded on behalf of himself and his colleagues, and concluded by proposing the final Toast, that of the Chairman, which was enthusiastically honoured.

Following the banquet, a dance was held, which continued until the early hours of the morning.

On August 28 the General Meeting was resumed in the Palace of the Nobility, and the proceedings terminated about 12.30 p.m. with the usual votes of thanks, which are recorded elsewhere.

In the afternoon, by the kindness of the Swedish Society of Engineers and Architects, automobiles were again placed at the disposal of the members, and under the guidance of Mr. K. Huldt, the President, and his colleagues, visits were paid to the following places of scientific and technical interest.

The Government Testing Institute.—The party was welcomed by the director, Professor Roos af Hjelmsäter, who gave a short account of the organisation and work of the establishment under his charge. He then personally conducted the visitors through the departments for testing materials, for engineering construction, which included a laboratory fully equipped for microscopic and metallographic investigations and for the heat treatment of iron and steel and other metals, and another for the testing of lubricants, bearing metals, and the like. They next visited the department for testing materials for building construction, such as building

stones, cement, concrete, &c. In another department were the chemical laboratories, where materials of an organic nature are tested.

The Royal Technical University.—Here the visitors were met by Professor H. B. M. Pleijel, Ph.D., Rector of the University, who welcomed them with a short speech, after which they were shown over the different departments—in particular, the well-equipped laboratories of the Royal School of Mines and the Metallurgical Laboratories, which were inspected under the guidance of Professor W. Petersson, Professor A. Johanssen, Professor J. A. Leffler, Professor D. Pétren, and Docent A. Grabe.

The Metallographic Institute.—Another group of members visited this establishment, which is under the charge of Professor C. Benedicks, Ph.D., Hon. Vice-President of the Institute. The party were received by Professor C. Benedicks and his fellow-worker, Dr. A. Westgren, and other members of the staff, and were shown over the laboratories and the library, where they saw much to interest them.

Banquet at the City Hall.

On Saturday evening, August 28, the President of the City Council, Mr. Allan Cederborg, and the City Council, invited all the members and their ladies to dine at the new City Hall, which in architectural magnificence and spaciousness probably outrivals any other civic hall in the world. There was again a brilliant assembly, which included Government officials and a number of prominent citizens of Stockholm, besides the members and their ladies. The guests entered the spacious Blue Hall, whence they ascended by the broad flight of marble steps to the reception rooms, and then proceeded to the Golden Hall, where the banquet was held. The details of the arrangements were carried out under the supervision of Mr. Engineer Nordgren. The Toasts of H.M. the King of Sweden, His Britannic Majesty, and the Heads of other States represented having been duly honoured,

Mr. Allan Cederborg (President of the City Council) proposed the Toast of the Iron and Steel Institute. He observed that from ancient times the extraction of iron and its refining had been one of the principal industries of Sweden. In the early

Middle Ages almost every yeoman in its ferriferous provinces had his own mine, worked it and sold his ore; but later they learnt to unite their forces in smaller or greater mining companies. These yeoman miners formed a kind of gentry. On several occasions they saved the country from a foreign yoke, and, on the whole, they represented through centuries some of the best elements of the Swedish nation. The restless technical progress of modern times had, in many respects, altered the conditions of the iron trade. New resources had been found; new methods and ways had been opened up. At the same time there was perhaps no market in which the after-war depression had made itself felt so heavily as in the iron industry. Hence it was more than ever necessary for its practitioners to follow the innovations made all over the world in order to be able to utilise every chance. A leading part in those efforts was taken by the Iron and Steel Institute. For nearly six decades that world-famous Association had, with growing vigour and enthusiasm, devoted itself to the promotion of the science of iron metallurgy. In the Royal Charter of the Institute it was emphasised that the Institute had most efficiently and successfully contributed to the material prosperity of England, and it might be willingly acknowledged that the work of the Institute had, in the same way, benefited all the world.

Sir W. Peter Rylands (President of the Iron and Steel Institute), in responding, tendered the grateful thanks of the members for the kind way in which the Chairman had submitted the Toast, and to the company for the cordial manner in which they had received it. He also desired to thank Mr. Cederborg for the compliment he had paid the members in proposing the Toast in the language of their country, in a manner which must have commanded the admiration of every Englishman present.

The Swedish people had overwhelmed them with hospitality during their visit. During the past few days they had indeed been entertained most royally, culminating in the present magnificent and brilliant assembly in the Golden Hall of the City, which imposed upon the visitors an obligation which they would find it hard to repay. He visited Sweden some fourteen years ago, when he was full of admiration for the beauties of Stockholm and

its surroundings, being much struck with the appearance of prosperity and contentment which was apparent on every hand.

It then occurred to him that it might be an advantage not to be so highly industrialised as they were in Great Britain, because the Swedish people might in that way be spared some of those difficult social problems which presented themselves in England. He had then thought that if he ever had to find another country, he would come and live in Stockholm. He had visited many lands since that day, but he had never observed any ground for altering the opinion he had then formed. In view of the intimacy of their engagements during the present week, he was strongly confirmed in the desire, if he might not be a Briton, let him be a Swede. There was much community of interest between the British and the Swedes; they had similar ideals and similar inspirations. The Chairman had referred to the cloud under which the great industry of iron and steel was suffering in Sweden. It might be a consolation to their Swedish friends to know that those engaged in the iron and steel industry in Britain were labouring under a cloud not dissimilar to their own. They were in that sense drawn even closer together as companions in a day of difficulty and trial; and the fact that there was a depression in the iron and steel trade in Sweden similar to that which was being experienced in Great Britain encouraged him to hope that the troubles arose from a similar cause, which it only required time to dissipate. He thought they might count upon it with hope and confidence that the great industry, so important to the Swedish nation, and equally important to his own, would have many bright days of prosperity before it. He hoped an opportunity might offer for the British members to repay in some small measure all the kindness which had been extended to them, and he could assure their Swedish hosts that their hospitality had been deeply appreciated and would always be treasured in their hearts.

Sir Hugh Bell, Bart., C.B. (Past-President), who was also called upon to respond, said he desired to refer to the present extraordinary situation in which the world found itself. Although Great Britain was suffering perhaps more directly than any other country from the circumstances to which he was about to refer, they were of a world-wide character and of far-reaching effect. The coal strike in Great Britain was as large a part of the

late war as any one of the battles fought on the plains of Flanders. The world was still suffering from that extraordinary destruction of wealth which went on for four years over what might be called almost the whole of the civilised world, involving the destruction of incalculable quantities of wealth, and, what was still worse, the loss of millions of precious lives. It was not surprising that the result of all that catastrophe, extending over years, should have left a situation as perilous as the present one—for he did not think anyone ought to disguise from themselves the fact that the situation was indeed a perilous one. How was that situation to be faced? Since he had been in Stockholm reference had again and again been made to the manner in which the circumstances ought to be dealt with so far as international relations were concerned, and he believed that such gatherings were by no means without their direct utility in bringing about a situation in which a solution would be found, if it were ever found, of the present difficulties. The closer the nations were drawn together by the ties of commerce, the more unlikely it was that they would be willing to break those ties and to proceed to the extraordinary folly which war, in any of its forms, meant to mankind at large. He had been careful to refer to war of all kinds. War between nations was bad enough, but war between classes was infinitely more damaging and more dangerous. What had been done in the past generation to produce a state of affairs in which there appeared to be an irreconcilable enmity between the two great classes which constituted human society—the immense class which laboured, and the lesser, but, he was inclined to think, much more important, class which devised and controlled? The best measures properly to divide the result of the product of industry among those two great classes had not perhaps been taken. Those of the members who had to undertake great enterprises knew that without accumulated wealth it was utterly impossible to undertake any such great enterprises as those which had brought about the civilisation the world now enjoyed. Were those things to be wrecked because they were unable to reconcile the differences which unfortunately existed all the world over between the two classes to which he had referred? There was a feeling of despair almost when one thought that the present civilisation, like many another, was about to collapse. But just as 1500 years ago the *pax Romana* which had dominated the civilised world broke up, and Europe

for some centuries was a more terrible place of abode than anybody could foresee, so it might happen again. It would not be the first nor yet the second time that it had happened. He had had the satisfaction that afternoon of once again visiting in Stockholm the most remarkable collection of prehistoric implements, and he had thought to himself, What had become of those people who, with the dawn of civilisation, contrived those extraordinary things which filled people to-day with wonder? With hardly any instruments at their disposal they did things which amazed the people of the present time. Through his daughter he had been made familiar with four or five other similar civilisations, spaced from one another by periods measured by thousands of years, and each one of them had disappeared so completely that it was not known at present who the people were that created them. Might it not be that the world was going through yet another of those crises, and that some of those present might live long enough to remember the pessimistic words that he was addressing to them? He thought it was not difficult to present the alternative. It was only necessary, in order to bring about a solution, to make up their minds that whatever was produced must pay for the whole cost of its production; that nobody could get anything for nothing—that it had to be paid for; and the present problem of the coal-owners of England was to persuade the men that any solution which did not take that into account was no solution at all. He ventured to say to the Swedish people that if they heard that the coal problem in England had been settled by the intervention of the Government, and by the payment of moneys from some other source than a ton of coal, that terrible day to which he had been referring was nearer at hand than any of them might believe. He hoped he would be forgiven for addressing, not without grave hesitation, such pessimistic words to so influential an assembly, and he therefore ended on a note which, at all events, partook rather of optimism than pessimism, by quoting a quatrain which was attributed to the present President of the United States:

> "A wise old bird sat on an oak:
> The more he saw, the less he spoke;
> The less he spoke, the more he heard—
> Oh, were I like that wise old bird!"

The Chairman said that it was strictly forbidden in the Stockholm City Hall to deliver too long or too many speeches, but he was sure it would be felt that he was doing his duty in breaking the rule by addressing a few words of congratulation to Sir Hugh Bell. Sir Hugh Bell was the senior of the company; he seemed to possess eternal youth, and it was a delight to the Swedish people to have him in their midst, because he was a friend of their nation. Sir Hugh Bell had stated at the banquet on the previous evening that he had now entered his second childhood. Whether that were so or not, certainly his memory in Stockholm would be eternal. The Swedish people who had attended the banquet would never forget that day, and would never forget the wise words which had been spoken to them by the representatives of a great nation.

Following the banquet, a dance was held in the Blue Hall.

Excursion to the Gustavsberg Porcelain Factory.

On Sunday, August 29, Mr. Axel W. S. Odelberg, Managing Director of the Gustavsberg Porcelain Works, invited the whole party to visit his factory at Gustavsberg, some sixteen miles down the fjord. On this day, as indeed on all the other days of the meeting, most beautiful weather prevailed. The members embarked on a steamer at the quay of Blasieholm at 10.30 a.m., and were met on board by Mr. and Mrs. Odelberg. The journey down the fjord was most enjoyable, and Gustavsberg was reached soon after midday. The party disembarked at the wharf of the factory, and were divided into groups for the purpose of more conveniently visiting the different departments. The showrooms were also inspected, which contained a large collection of the products of the firm, including specimens of manufactures during the last one hundred years. The exhibition contained many beautiful objects of art, and there was also a considerable display of the chinaware of everyday use. Finally the visitors were taken to see a newly installed electrically heated kiln.

Mr. Odelberg, addressing the party, remarked that the pottery trade was certainly one of the oldest, and one of the most useful

arts. It had reached a high state of development thousands of years before man knew anything about the production of iron, though the latter article might now be of greater importance to civilisation. He would like to mention the name of one great man, Josiah Wedgwood, the founder of the modern pottery industry. When the Gustavsberg factory was founded about one hundred years ago pottery was produced on the lines indicated by Wedgwood. Since then they had endeavoured to exchange ideas with other nations to their mutual benefit. The electrically heated kiln which was now witnessed at work was constructed by Mr. C. W. Speirs of the Morgan Crucible Company, Battersea—that was to say, he constructed the electrical part, and he (Mr. Odelberg) was responsible for the ceramic details. The kiln was built on the tunnel principle, ninety-six trucks being fired in eight hours, or about one truck holding thirty cups every five minutes. The trucks were pushed through the kiln by an electric motor, and the resistors at the top of the tunnel and in the middle of it heated the ware as it passed through. The consumption of electric current was about $1\frac{3}{4}$ kilowatt-hours per dozen cups, and electric and optical pyrometers were installed for the control of the temperature. The kiln was used for the glost firing of earthenware and china cups, the maximum temperature reached being about 1100° C. The loss in "seconds" or breakages was almost negligible, being considerably under 1 per cent. No saggars were used, the cups being placed on fireproof insulating slabs on the trucks. Since the atmosphere in the kiln was perfectly pure, the most delicate underglaze colours and decorations could be produced without difficulty.

While the tour of the pottery works was in progress, the electric kiln had been put to work on the glazing and finishing of a large number of small porcelain trays of blue and pink patterns, bearing an inscription commemorative of the visit. As car after car full was withdrawn, the trays, still hot from the kiln, were distributed among the guests as mementoes of their visit.

On re-embarking the whole party was entertained to luncheon on board by Mr. and Mrs. Axel Odelberg, and the steamer then made a tour of the islands of Ingaröfjärden, and finally landed the passengers at Saltsjöbaden, whence they returned to Stockholm by electric train.

EXCURSIONS TO WORKS AND MINES.

The days immediately following the meeting in Stockholm, Monday, Tuesday, and Wednesday, August 30, 31, and September 1, were devoted to visits to the chief centres of the Swedish iron and mining industries. Elaborate arrangements had been planned by the Reception Committee, and extensive preparations were made for the comfort of the members taking part in them. Two excursions were organised: (1) to Grängesberg, Domnarfvet, Falun, Hofors, Sandviken, and Gävle; (2) to Degerfors, Bofors, Hellefors, Skoghall, Hagfors (Uddeholm), and Fagersta.

Two special trains were provided for the parties, free of charge, by the Swedish State Railways and by the private Railway Companies named in the following pages. Throughout the whole journey the members were the guests of the various companies whose works they visited, and were entertained in a most generous and lavish manner, in several instances at the private mansions of the managing directors of the various establishments visited during the day.

Excursion I.

The special train consisted of sleeping-cars of the most luxurious type, with a day coach attached, and was used throughout the journey. It was provided free of charge by the Swedish State Railways, and by the following private companies: the Stockholm-Västeras-Bergslagens Railway, the Gävle-Dala Railway, and the Uppsala-Gävle Railway. The sleeping-cars were at the disposal of the members for each night's rest, and no change of train occurred.

Itinerary.

Sunday, August 29.

11.20 P.M.	Departure from Stockholm.

Monday, August 30.

5.36 A.M.	Arrival at Grängesberg.
8 A.M.	Breakfast, by invitation of the Grängesberg-Oxelösund A.B.
8.45–10.50 A.M.	Visit to the mines.
11 A.M.	Departure from Grängesberg.
12.30 P.M.	Arrival at Domnarfvet.
12.35 P.M.	Lunch, by invitation of the Stora Kopparbergs Bergslags A.B.
2–4.25 P.M.	Visit to the Domnarfvet Steelworks.

Monday, August 30 (cont.)

4.43 P.M.	Departure from Domnarfvet.
5.10 P.M.	Arrival at Falun.
5.15–6.45 P.M.	Visit to the mines and the industrial museum.
7.30 P.M.	Dinner, by invitation of the Stora Kopparbergs Bergslags A.B.

Tuesday, August 31.

7.40 A.M.	Departure from Falun.
8.35 A.M.	Arrival at Hofors.
8.40 A.M.	Breakfast, by invitation of the Hofors Steelworks.
9.20–11.50 A.M.	Visit to the Hofors Steelworks.
12 NOON.	Departure from Hofors.
12.53 P.M.	Arrival at Sandviken.
1 P.M.	Lunch, by invitation of the Sandviken Steelworks.
2.15–5 P.M.	Visit to the Steelworks.
5.5 P.M.	Departure from Sandviken.
5.35 P.M.	Arrival at Gävle.
7.15 P.M.	Dinner, by invitation of the Stora Kopparbergs Bergslags A.B., the S.K.F. Hofors Steelworks, the Sandviken Steelworks, and the Ljusne-Woxna A.B.

Wednesday, September 1.

8.33 A.M.	Departure from Gävle.
9.5 A.M.	Arrival at Alvkarleö.
9.10 A.M.	Breakfast, by invitation of the Swedish Board of Waterfalls.
9.45–10.55 A.M.	Visit to the Power Station.
11 A.M.	Departure from Alvkarleö.
12.30 P.M.	Arrival at Dannemora.
12.35 P.M.	Lunch, by invitation of the part owners of the Dannemora Mines.
1.15–4.15 P.M.	Visit to the mines or to the Österby Steelworks.
4.17 P.M.	Departure from Dannemora.
6.50 P.M.	Arrival in Stockholm.

At 11.20 P.M., on Sunday, August 29, the following group, consisting of thirty-eight members and partakers in all, left Stockholm, following the route planned for Excursion I.:

Adamson, G. R.
Banks, A. R.
Bramley, Dr. Arthur
Brearley, Harry (Member of Council)
Chattin, A. E. (Assistant Secretary)
Clasen, B.
Clasen, Leo (jun.)
Cleland, W.
Desch, Prof. Cecil H. (Member of Council)
Eckermann, Dr. Harry von
Elsdon, R. (Librarian)
Else, L. H.
Etchells, H.
Fairholme, F. C.
Firth, Wybert
Grabe, Alf G. (Hon. Secretary of the Meeting)
Graves, H. G.
Habershon, A. R.
Hatfield, Dr. W. H.
Hill, William
Jones, E. Peter
List, Paul
Lockley, H. H. L.
Louis, Prof. Henry (Vice-President)
Marsh, F. S.
McCloskey, T. D.
Nishimura, K.
Pollock, T. F.
Rothera, L.
Sahlin, Carl
Sahlin, E. G. (Consul-General in London)
Saniter, E. H. (Member of Council)
Sjögren, Arvid
Steel, Ronald
Stromeyer, C. E.
Toy, H. B. (Hon. Member of Council)
Upton, A. E.
Wilkinson, W. H. (Sheffield)

The Grängesberg Mines.

The train arrived at Grängesberg early on the morning of Monday, August 30. The party were met by Mr. N. Hedberg, General Manager of the Grängesberg-Oxelösund Company, and other officials. They proceeded by automobiles to the Company's Hotel, where breakfast was served, immediately after which they were conducted to the mines, which were decorated with flags for the occasion. A short pause was made *en route* in order to inspect the workmen's dwellings, and the Cassel Donation founded by the late Sir Ernest Cassel. Mr. Hedberg, General Manager, Mr. B. Anderson, the Chief Engineer, and the Engineers, Messrs. W. Fredenberg and Nordenström, acted as guides, and showed the party over the underground works and surface plant.

The Grängesberg Mines are located in the district of Grangärde, in the southernmost part of Dalarne, about 45 miles south-west of Falun. The ore deposits of Grängesberg were known and worked at least as early as 1584. Down to about the middle of the eighteenth century the ore was extracted in a very primitive and wasteful fashion—on open stopes. This method was continued, with successive improvements, right down to the end of the nineteenth century. In the seventies a railway system connecting the mines with the centre of the iron-working district and with the port of Oxelösund on the Baltic was constructed with British capital, and was taken over by a British company. Sir Ernest Cassel, divining that the basic process (invented in 1878) would create a big demand for highly phosphoric ore, so abundantly found at Grängesberg, induced the British company to buy up most of the Grängesberg Mines and to promote the formation of a mining company, which was named Grängesbergs Grufve A.B. (established in 1883). The Swedish company, now commonly known as the Grängesberg company, whose full name is Trafikaktiebolaget Grängesberg-Oxelösund, was formed in July 1896, and acquired all the shares in the Grängesbergs Grufve A.B., and all the British shares in the railways. In 1903 the Grängesberg company acquired the principal interest (shared with the Swedish Government since 1907) in the far bigger iron ore mines at Gellivare, originally developed with British capital, and Kiiruna, in

Lapland. From that time Swedish iron ore began to be exported on a really extensive scale.

The Grängesberg mining-field is the principal part of an almost unbroken chain of ore deposits extending from Lake Norra Hörken to Gräsberg, for a length of nearly 20 miles. The Grängesberg deposits are closely packed together within an area having a length of 4500 metres and a breadth of 400 metres, the principal ones being contained in the so-called Export Field, which is a group of mines consisting of the North and South Field (and an intermediate field), the Strandberg Field, and the Timmer Mines (the large ore deposits of which were discovered in 1911). The North Field forms practically one continuous layer of ore, with a length of 420 metres and a breadth of 80 metres. The ore of the Export Field is of two different kinds—viz. (1) the so-called "apatite-ore," which is a fine-grained magnetite, generally containing 62 per cent. of iron and 0·8 to 1 per cent. of phosphorus; and (2) the so-called "segmalm," which is a thin slaty red hæmatite, containing as a rule from 0·07 to 0·30 per cent. of phosphorus. The "country rock" is leptite (fine-grained gneiss), layers of which, of varying thickness, are also found here and there embedded in the ore. The ores are, moreover, traversed by fine to thick veins of pegmatite. The deposits have a dip of about 70 degrees to the east. The Export Field has a total area of approximately 82,000 square metres.

The other mines—namely, the North Hammargrufve, Risberg, Ormberg, and Lomberg fields—are much smaller. The ore there has a lower content of phosphorus and is as a rule used for home consumption. The ore bodies are lenticular, and the deposits likewise have a dip of about 70 degrees to the east. Explorations completed in 1913 showed that at a depth of 500 metres the total ore area extends to at least 86,800 square metres. The total amount of ore in Grängesberg down to a depth of 500 metres is estimated at present to be approximately 150 million tons.

Since 1900 all mining at Grängesberg has been carried on underground. At the present time mining in the North and South Fields and the Strandberg Field is proceeding at a depth ranging from 150 to 190 metres, and in the Timmer mines at a depth of 93 to 150 metres. The method first adopted was that of shrinkage stoping, with wide chambers and narrow pillars, but it was not a

success, chiefly owing to the weakness of the hanging wall. In 1906 it was modified by combining shrinkage stoping with the slicing of broader pillars, both the chambers and the pillars being 10 to 12 metres in breadth. This method likewise had to be abandoned (except in the southern extremity of the South Field), chiefly because of the difficulties encountered in clearing the chambers. The system eventually adopted and at present generally in use is a modification of the American system of sub-level slicing, adapted to suit the harder Swedish ores. Four forms of this system have been developed, which differ with regard to the breadth of the pillars, depending upon the different strengths of the rock. In all four methods the "slices" are as a rule 5 metres in height (the cross-level being 2 metres in height, and the roof 3 metres). The ore is loaded on to trucks carrying about 3 tons, and hauled by electric engines, driven by continuous current, seven of which are in continuous service per shift. It is hoisted in skips carrying 5 to 7 tons, and dumped into pockets at the shaft-head, 25 metres above the surface of the ground. It first passes through grizzlies with openings of 450, 150, and 50 millimetres. Rock exceeding 150 millimetres is crushed to that size. Rock of 150 to 50 millimetres is passed first through magnetic drums, in which the magnetic iron ore is separated, and the non-magnetic ore passes to a belt conveyor, where the waste is removed. Rock of less than 50 millimetres proceeds to the ore-dressing plant. The ore and waste fall into different pockets, from which the products are dumped into railway trucks. The small-sized rock is first passed through a series of sieves for the purpose of grading. Each grade is then passed through magnetic ore-separators, in which the magnetic ore is separated. The non-magnetic material is transferred to jigs, for the purpose of separating the hæmatite from the waste. The different products are dumped into pockets, from which they are loaded direct into railway trucks.

The rate of flow of water in the Export Field is normally about 1300 litres per minute. All the water above the level of 230 metres is conducted to two basins, one at the Müller shaft (capacity 2500 m.^{3}), the other at the Carl Johan Shaft (capacity 2000 m.^{3}), from which the water is raised to the surface by centrifugal pumps, lifting 5000 litres per minute. Each of the

basins is provided with a reserve centrifugal pump, with a capacity of 2000 litres per minute. No artificial ventilation is required in any part of the mines. Electric lighting is installed in the shafts and main levels. The total quantity of ore mined in the Export Field down to 1925 inclusive was 25,885,113 tons. The present annual output of ore from the Grängesberg mines is approximately one million tons.

On the termination of the visit to the Mines, Professor Henry Louis, Vice-President, expressed the hearty thanks of the party to the Grängesberg Company for their kind hospitality, and the train was then taken for Domnarfvet, which was reached shortly after midday.

Works of Stora Kopparbergs Bergslags A.B., Domnarfvet.

On arrival at the station, the party was welcomed by Mr. E. Lundqvist, Managing Director of the Stora Kopparberg Company; Mr. H. Almqvist, Chief Engineer of the Works; Mr. A. Bywall, Manager of the Kvarnsveden Paper Mills; Mr. A. Fahlcrantz, Sales Manager of the Company; Mr. G. Frisell, Commercial Manager; Mr. F. von Homeyer, Chief Metallurgist; and Mr. A. Hultgren, Metallurgical Engineer at Söderfors Steelworks. Motor-cars conveyed the members to the Stora Kopparberg Company's hotel. On the way a halt was made to permit of an inspection of the baths and hospital established by the company, the workmen's dwellings, and the company's school. They then continued the journey to the hotel, where lunch was partaken of by invitation of the Stora Kopparberg Company, after which the party proceeded on foot to the works.

The iron and steel works at Domnarfvet were erected in the years 1873–1878, when the Stora Kopparbergs Bergslags Aktiebolag concentrated there the greater part of its iron industry which previously had been carried on at a number of small works of old type. The ores were obtained from mines in the district. Charcoal was chiefly obtained from adjacent forests. In order to ensure the supply of charcoal, large charcoal kilns with by-product plants were erected at the steelworks in the years 1892–1895. This plant has in later years been rebuilt at Bysjön, further up the river. Through the purchase of important parts

of the Grängesberg mining-field in the south of Dalarne, the company came into possession of suitable raw material for the basic Bessemer process. About half of the ore supply in Grängesberg is now owned by the company. In 1898 a basic Bessemer plant, consisting of four converters of 9 tons each, was built. Simultaneously an open-hearth plant, comprising four furnaces of 20 tons and a steel foundry, was erected.

The comparatively big converter plant demanded a large blast-furnace production, and in 1898 it was decided to replace charcoal by coke. It was not until 1911, however, that coke was exclusively used, and the blast-furnaces were then rebuilt to suit that fuel. Experiments on the production of pig-iron in electric reduction furnaces commenced in the years 1907–1908, and the first large electric reduction furnace according to modern principles was built in the years 1910–1911. The iron and steel works were originally planned for using water-power direct from the river Dalälven close by. In order to satisfy the Company's increased need of power, hydro-electric power stations began to be erected at the waterfalls of Dalälven about the later years of the nineteenth century. After completing the last modern power station, Forshuvudforsen, the company in this district has available 90,000 hydro-electric horse-power.

The company's iron and steel works at Domnarfvet have been enlarged many times, and the yearly capacity is at present about 100,000 tons of finished steel. The works consist chiefly of the following equipment:

An electric smelting plant comprising four shaft furnaces, each with a power input of about 6000 kilowatts and producing about 18,000 tons of pig-iron a year. The incoming primary current of 10,000 volts is transformed down to the operating voltage of the furnaces, *i.e.* 60 to 120 volts. There are 8 electrodes per furnace, which are of the Söderberg continuous, self-baking type. The reducing agent in these furnaces is charcoal. The smelting plant contains further two ferro-alloy furnaces, each of 1000 kilowatts capacity, and a blast-furnace plant with five small furnaces, each with an output of about 25,000 tons of pig-iron a year. The coke is either imported or obtained from the coke-oven plant at the Oxelösund Ironworks. At present only two furnaces are in blast, until the hydro-electric power plants have been sufficiently

enlarged and the electric iron-ore reduction has been technically so improved as to admit of the total iron production being electrified. A hot metal mixer of 250 tons capacity, of the rolling type is firedwith gas from the electric pig-iron furnaces. To this mixer is carried all the iron from the coke blast-furnaces and part of the electric charcoal pig-iron. The other part of the electric pig-iron is blown directly for producing a special refined quality of extra soft steel. There is also a basic Bessemer plant containing four converters of 14 tons capacity, and a dolomite plant for the manufacture of lining material for the converters. Soft steel produced from pure electric charcoal pig-iron is of the following composition :

	Per Cent.
Carbon	0·05
Manganese	0·35
Phosphorus	0·050
Sulphur	0·005

There is, besides, an open-hearth plant with one 30-ton and one 20-ton furnace melting bulky scrap from their own rolling-mills, and an electric steel plant with one 20-ton and one 5-ton electric furnace. The larger furnace is used partly for melting scrap, partly for refining charcoal basic pig-iron. For the extra soft qualities of press plates, welding rods, &c., the refining is carried so far that the following analysis is obtained :

	Per Cent.
Carbon	0·03
Manganese	0·016
Phosphorus	0·015
Sulphur	0·005

For special qualities of steel, recarburising is effected in the furnaces with pig-iron or anthracite. The small 5-ton furnace is used for special charges in the steel foundry. The rolling-mill department contains a cogging-mill, a rail and beam-mill, a universal plate-mill, two sheet-mill trains with 26-inch rolls driven by water-turbines, another plate-mill, a rod-mill, five merchant bar-mills of different sizes, a steel foundry, and a nail and bolt factory for the manufacture of nails, rail spikes, rivets, and bolts.

The basic slag works yield about 10,000 tons of phosphate

per annum, corresponding to about 75 per cent. of the phosphorus contents of the ore.

Apart from the charcoal which is burnt in the forests and carried by horse or by rail to the steelworks, Domnarfvet obtains charcoal from the company's charcoal plant at Bysjön, about 4 miles from the works and connected therewith by a special line. The charcoal kilns are of the horizontal canal type, where the distillation gases circulate through a condenser tower (for removing the by-products—tar, turpentine, methyl alcohol, and acetic acid), through heating chambers, and back to the kiln in the direction opposite to that in which the wood is moving. The capacity of the plant is about 15,000 tons of charcoal a year. The steelworks further derive about 7500 tons of charcoal a year from the forests, making a total quantity of about 22,500 tons, sufficing for the production of 60,000 tons of electric pig-iron.

The electric power for the steelworks is supplied by the company's three hydro-electric power stations in Dalälven, from which Domnarfvet obtains about 42,000 electric horse-power, distributed in the following manner:

	Electric Horse-power.
To the electric shaft furnaces	25,000
To the electric steel furnaces	7,000
To motors, &c.	10,000

The works furnish structural steel, steel for forgings, sheets, plates, and wire for the Swedish market. A very small part is exported, namely, the steel made from charcoal basic pig, on account of its excellent properties for forging and as welding rods.

For the workmen and staff and their families the company has erected baths, hospitals, convalescent homes, a kindergarten, summer resorts for children, industrial training schools for boys and girls, domestic schools for young women, libraries, &c. Before employing a youth in the works he has to pass tests of intelligence and character. If he shows fitness for leadership, he is given a chance to go through a special school for training as a foreman. If he has devoted the better part of his life to the company's service he can retire at sixty-five years of age with a pension. The greater part of the workmen and staff are living in houses belonging to the company, or in their own houses built with financial assistance from the company.

On leaving the works, the members proceeded by car to the Forshuvudforsen Power Station and the Kvarnsveden Paper Mills. Here Mr. Miede and Mr. Lindell acted as guides and conducted the party through every department of the paper-mills, where they witnessed all the various operations involved in paper-making, the details being fully explained in the most courteous manner. They then proceeded to the station, and at 4.40 P.M. took the train for Falun, arriving at 5.10 P.M.

The Falun Mines.

The train was taken direct to these celebrated mines, and on alighting the members were greeted by the shattering reports of a volley of mining cartridges. They were welcomed by Mr. P. A. Jonsson, manager of the mines, and a number of other officials. The mine is the oldest industrial enterprise in Sweden and is rightly called "the cradle of Swedish industry." The oldest known document relating to the mine, and to the company which still owns it, the Stora Kopparbergs Bergslags Aktiebolag, dates from the end of the thirteenth century. From the document it appears, however, that copper-mining had regularly been carried on very much earlier. The mine reached its chief importance during the seventeenth century, when it was the largest producer of copper in the world—a fact which stood in close relation to Sweden's position as one of the Great Powers of Europe. The richest copper ore having been extracted, the owners of the mine directed their interest towards new lines of activity, and in the eighteenth and nineteenth centuries there was gradually developed the modern industrial enterprise, known as the Stora Kopparbergs Bergslags Aktiebolag. The Falun mine is now principally worked for iron pyrites, of which the yearly production is at present about 70,000 tons. The sulphur content averages 38 to 40 per cent. An important part of the pyrites is used in the company's own pulp mills, and in the plant for the production of sulphuric acid. From the Falun mine and industries dependent thereon are further produced iron and copper sulphate, red paint, aluminium sulphate, talc, and, as a by-product from the copper sulphate production, small quantities of gold, silver and bismuth.

The Mining Museum.

After making the tour of inspection of the mines, the party were shown over the historical mining museum by Mr. A. Silow, Chief Librarian and Curator. This museum is situated in the former head offices of the Company at the Falun mine, and its purpose is to show the historical development and present standing of the Falun mine and other branches of the company's activity, The museum was founded during the last years of the nineteenth century; it was reorganised in 1922 and is still developing. In a special room are placed models constructed by the famous Swedish mechanic, Christopher Polhem, who was engaged at the mine at the beginning of the eighteenth century. The concentration and treatment of copper ore during the different ages is shown. The most highly refined product from the copper mines in olden times was the coinage. From the beginning of the seventeenth century to the end of the nineteenth century all Swedish copper coins were made of copper from the Falun mine, and most of them in the company's own mint at Avesta in the province of Dalarne. Of special interest is the exhibit of "plate coins," of which the largest (10 daler silvermynt) weighs about 40 lbs., and was manufactured in the middle of the seventeenth century. Ancient Swedish iron-making is represented by models of primitive furnaces (*blästerugnar*), and samples of iron therefrom. Further, there are illustrated different types of Swedish blast-furnaces as built in Dalarne, from the old timbered shafts to the electric smelting furnaces. In the section for forestry and the wood industry the exhibits show old and new methods of making charcoal, still one of the chief raw materials of the Swedish iron industry. Charcoal-making, and the chemical industry connected therewith, play an important part in the company's exploitation of its vast forests (about 900,000 acres), from which are further produced sawn and planed timber (yearly production 35,000 to 40.000 standards), sulphite and sulphate pulp (about 50,000 tons), newsprint paper, wrapping paper, and pasteboard for use in house construction and decoration (about 60,000 tons), &c. Finally the museum contains a map demonstrating the company's supply of water-power, and models of the different types of power stations, amongst others the Forshuvudforsen station which supplies the energy for

the electric reduction furnaces at the Domnarfvet Steelworks. The total supply of water-power available amounts to about 200,000 horse-power, of which at present 110,000 horse-power is harnessed.

On completion of the visit, the members proceeded by train to Falun Railway Station; here they again found automobiles in readiness to convey them to the head office of the Stora Kopparbergs Company, where, by invitation of that company, the whole party was entertained to dinner in the Banquetting Hall. Mr. Lundqvist, Managing Director, presided, making a speech of welcome to his guests, to which Professor Henry Louis and Mr. H. B. Toy replied on their behalf. During the dinner the members were entertained by a choir of Dalecarlian musicians, who played old-time national folk melodies, and Mr. Ingenjör Sjöberg also delighted them with Swedish songs of the eighteenth century. For the occasion of the dinner, the centre of the hall floor had been specially painted with a map of the district, showing the situation of the company's many properties, and in the four corners of the room were placed lumps of iron ore from the company's mines. One interesting incident during dinner was the distribution of photographs taken that morning, together with copies of the Stora Kopparberg edition of *The Times*, specially printed by the company. On the conclusion of the banquet, the members returned to their special train, which remained on a siding in Falun Station throughout the night, the street traffic having been diverted to ensure to the party a good night's rest. Hofors was reached next morning (Tuesday) about 8.35 A.M.

S.K.F. Hofors Steelworks.

On Tuesday, August 31, on arrival at Hofors, Mr. Hjorth, the Managing Director, and Mrs. Hjorth welcomed the visitors at their own house, and entertained the whole party to breakfast. During the meal Mr. Davidson, Technical Manager, took the opportunity to outline, in a short speech, the leading features of the Hofors Steelworks. The visitors then proceeded to the works, where they were joined by Captain Dahlbeck, Director of S.K.F., and the morning was devoted to an inspection of the works.

The Hofors Steelworks are situated near Hofors station on

the Gävle-Dala Railway. The works are connected with the station by a standard gauge railway nearly 2 miles long, owned by the company. The steelworks, which are the oldest in the province of Gästrikland, were founded during the first half of the seventeenth century. Originally a primitive plant run by small local ironmasters, it came at an early date into the possession of the Petré family, who remained the owners for about two hundred years (until 1878). The development of Hofors into a modern steelworks commenced with the erection of a Bessemer plant with two converters which was started in 1884. An up-to-date and powerful ingot rolling-mill was completed in 1885, and the power supply available from the waterfall then harnessed was fully employed. Additional power was obtained in 1894 by means of electrical transmission from a waterfall with a 30-metres head, and was employed for three new rolling-mills which were started in 1896–1897. These mills were, in fact, the first in the world driven exclusively by means of electricity. The two waterfalls mentioned above supply together about 3000 horse-power. In addition, Hofors now consumes the power from a waterfall with a 20-metres head situated about 4 miles distant from the works. The works also receive power from the State power station at Älvkarleby, from which 1300 horse-power is purchased. The power supply is supplemented by a 650 horse-power auxiliary steam-power plant.

The present equipment of the steelworks consists of two blast-furnaces, with roasting kilns and sintering works, three acid open-hearth furnaces of 15 tons each, and one basic furnace of 25 tons, cogging, medium, fine and wire rolling-mills, a wire drawing-mill, a hydraulic press, five forging presses, and other plant, with a foundry and machine shop, as well as various auxiliary machines. The works have at present an annual capacity of about 28,000 tons of rolled products. Hofors steel ranks in quality among the best in Sweden, and enjoys an old-established reputation for being able to satisfy very stringent requirements. Under normal conditions a considerable part of the output is sold to various foreign markets, especially in the form of tool steel, rolled and forged, wire rods, hoop steel and hollow drill steel. The process of concentration of small plants has gradually led to closing down the works not situated in

Hofors. An exception is formed so far by Uhrfors, where the manufacture of horse-shoes was taken up and is still carried on. The factory, started in 1882, is the oldest and largest of its kind in Scandinavia.

In 1916 the steelworks were bought by the S.K.F. Ball Bearing Co. The magnificent expansion of this company's world-renowned manufacture of ball-bearings made it necessary to secure a regular supply of high-grade steel. Large new works, with a forging press, cold rolling and wire drawing mills and annealing department, were erected in the years 1916–1918. The Hofors Steelworks own land of a total area of about 25,000 hectares (62,000 acres). The wood products are worked up in the company's own saw-mills, situated at the Hofors railway station; they are electrically driven, and equipped with three frames and a planing mill.

At the close of this very interesting visit the guests took their seats in the special train, and departed for Sandviken, which was reached at a few minutes before 1 P.M.

Sandvikens Jernverks A.B.

On arrival at Sandviken the guests were welcomed at the station by Mr. Tord Magnuson, Chairman of the Company, and Mr. Lars Yngström, Technical Director of the Works. The members were first entertained to luncheon at the private residence of Mr. K. F. Göransson, Managing Director, and Mrs. Göransson. It is interesting to recall that Mr. K. F. Göransson is the grandson of G. F. Göransson, who played such a prominent part in the development of the Bessemer process, and whose successful trials with that process in 1858 at Sandviken enabled him to start the Sandviken Steelworks on their prosperous career. At each cover at the luncheon table were placed a menu card and table card, composed of very fine sheets of Sandviken steel on which were printed the menu and the guest's name, and they were carefully preserved by the visitors as a treasured memento of the occasion.

The Sandviken Steelworks, compared with most other Swedish steelworks, are comparatively young, being not yet quite sixty-five years old, but the works are nevertheless the largest high quality steelworks in Sweden located in one place. The first

company, the Högbo Stål och Jernverks Aktiebolag, was formed by Göransson in 1862 and a plant was erected at Sandviken, situated on Lake Storsjön near the Gävle-Dala Railway. The present company, Sandvikens Jernverks Aktiebolag, was formed in 1868.

The ore is obtained mainly from mines in Central Sweden, of which the company is a part-owner. This ensures a regular and permanent supply of the high quality ore on which production has always been based. For the blast-furnaces, charcoal is the only fuel used. The yearly consumption is about 200,000 cubic metres. Only a small portion of this can be supplied from the forests of the company, the greater part being obtained from the provinces in the north and north-west. Wood is extensively used for the open-hearth process, but also a mixture of wood and coal where this is possible with regard to the quality of the steel. In the earlier days of the company rolled railway tyres were a speciality, a product at that time only made by two other works in Europe, one in England and one in Germany. In 1907 this manufacture ceased, the steel-making methods in foreign countries having been developed to such an extent that they were able to satisfy all demands as to quality. The more expensive Sandvik steel was consequently no longer in demand for this purpose. The same thing repeated itself with regard to heavy machinery forgings, once one of the principal products of Sandviken. The company had to take up the manufacture of other kinds of articles where the quality of the steel is of greater importance than is generally the case with large forgings.

Sandviken was one of the first steelworks in the world which made a speciality of cold-rolling and hardening band steel. The first cold-rolling mill in Sandviken was erected in 1882. Since then this line of manufacture has constantly developed. Cold-rolled, hardened, and tempered bands 600 millimetres wide, 1 millimetre thick, and about 100 metres long for conveyors are now regularly manufactured. Hardened and tempered steel bands for power transmission are also a speciality of Sandviken. The thinnest bands now rolled commercially have a thickness of 0·009 millimetre. Other specialities are the so-called "Paragon" hardened and tempered wire for umbrellas, flat wire for clock springs, &c.

In 1889 Sandviken started to manufacture hot-rolled weldless

tubes, and erected the first plant of this kind in the country. Their manufacture is still one of the company's most important specialities, but the bulk of the products no longer consists of soft or medium-soft tubes but material of higher grade, such as hollow steel for ball-bearing races, different kinds of alloy steel tubes, &c. Hollow rock-drill steel is another speciality where the quality of the material is of importance for the efficiency of the drills. Alloy steels for automobiles and the aviation industry are other important fields of the company's activity. Finally the company has also to a certain extent taken up the production of finished articles from cold-rolled material, such as band saws, felling saws, hardened (but not ground) razor blades, main springs for clocks, watches, &c.

The chief equipment of the Sandviken Steelworks consists at present of four blast-furnaces with three roasting furnaces and one ore briquetting plant ; a Bessemer plant with two acid converters, each of 4·5 tons ; an open-hearth plant with four acid and two basic furnaces, each of 15 tons ; one electric furnace of 4 tons ; hot-rolling mills, comprising one cogging-mill, two tool steel mills, one wire mill, two band mills, and five tube mills ; a cold-drawing plant for tubes and bar steel ; a finishing plant for tubes and for the manufacture of tube elements ; one forge with eight steam hammers ; one hydraulic press of 2000 tons ; a wire-drawing mill with seventy-five drawing drums ; a cold-rolling plant with 137 pairs of rolls ; a band and wire-hardening plant with thirty-four furnaces, and a polishing plant for hardened band steel ; a plant for paragon wire ; a plant for the manufacture of silver steel ; a saw factory, and a spring factory. For repairs and for the production of machinery for their own use the works are further equipped with the usual modern auxiliary shops, a saw mill with a capacity of 50,000 logs a year, and other wood-working plant. An important accessory to the works is the new laboratory, erected in 1920, for physical and chemical research, which may be regarded as one of the best-equipped metallurgical laboratories in the country.

The productive capacity of the works is 28,000 tons of pig-iron and 55,000 tons of ingots a year. The electric motors of the works have a total capacity of 23,000 horse-power. This power is furnished from the river Dalälven and on this river, at the falls of

Lanforsen, the company, in co-operation with the city of Stockholm, is now erecting a power station designed for a capacity of 36,000 kilowatts. For reserve power Sandviken has a station with steam-turbines of a capacity of 4000 kilowatts. The workmen at Sandviken now number slightly over 3000. About half of these live in houses owned by the company, and of the rest over 400 own their own separate houses, built by the workmen themselves with the assistance of loans by the company. Further, the company has built and supports schools, a church, baths, a theatre and lecture hall, a library, sports grounds, parks, hospitals, &c. A visit to the community of Sandviken certainly leaves a strong impression of the company's activity in this respect.

On the conclusion of the visit the members took the train to Gävle, where they were entertained in the evening to dinner at the hotel by the Stora Kopparbergs Company, the S.K.F. Hofors Steelworks, the Sandviken Steelworks, the Ljusne-Woxna Company and the Forsbacka Steelworks. Immediately before dinner was served, Dr. H. von Eckermann exhibited two kinematograph films; the first one illustrated the methods of manufacturing Swedish iron by the Lancashire process at the works of the Ljusne-Woxna Company; the second film demonstrated the variations in the phosphorus content of growing timber during the different seasons, and the methods adopted at the Ljusne Works for reducing the phosphorus in Swedish iron by using charcoal made from wood cut at the season when it contained a minimum amount of phosphorus. It will be remembered that this subject was dealt with very fully by Dr. von Eckermann in a paper presented to the Institute in 1925. At dinner Mr. Göransson, Managing Director of the Sandviken Steelworks, presided, and Mr. T. Magnuson in a short speech bade the members a hearty welcome, and proposed the Toast of "The Iron and Steel Institute." His Excellency, Mr. Lübeck, *Landshövding* (Governor) of the province of Gästrikland also addressed the company, and Mr. H. Brearley, Member of Council, replied for the guests. After dinner Mr. Göransson produced for the interest of the visitors the original contract made between Sir Henry Bessemer and Mr. G. F. Göransson.

The night of Tuesday, August 31, was spent in the sleeping-cars at Gävle station, and the same consideration was shown for

the visitors as at Falun, all street traffic being diverted from the vicinity of the station. The departure from Gävle was made at 8.33 A.M. on the following morning, Wednesday, September 1.

Älvkarleby Power Station.

On Wednesday, September 1, a halt was made at Älvkarleö for breakfast, and afterwards the party made a thorough inspection of the Älvkarleby Power Station under the guidance of Chief Engineer A. Lundqvist. The undertaking is owned by the Swedish Government, and is worked under its direction. The Älvkarleby Power Station utilises the lower portion of the Dal river about 8 km. from its mouth, and its distribution system covers an area of about 25,000 square km. The building was commenced in 1911, and the plant was put into operation in 1915. The total length of the dams is about 800 metres. The length of the intake canal is about 250 metres, and its area at normal water-level is about 300 square metres. The power house has five open turbine chambers, each $25 \times 7 \cdot 5 \times 20$ metres, erected close to the machinery hall with an area of 14×60 metres. The machinery consists of five horizontal double twin turbines of the Francis type, each of 15,000 horse-power at 150 revolutions per minute, five three-phase generators of 14,000 k.v.a. each at 11 k.v., 50 cycles, with directly coupled exciter dynamos. The output for the year 1923 was: maximum load, 59,300 kilowatts; power production, 226,373,000 kilowatt-hours.

Dannemora.

Dannemora was reached at 12.30 P.M. on Wednesday, September 1. Baron Beck-Friis, owner of the Harg Works, Mr. Sundberg, Manager of Gimo-Österby Works, Mr. Danielsson, Mr. Gumaelius, Chief Engineer, and Mr. Dellwik, Manager of the Mines, greeted the party on arrival. Lunch was served by invitation of the Dannemora Company at the Assembly Hall, the Chair being occupied by Baron Beck-Friis. During the luncheon he proposed the Toast of "The Iron and Steel Institute" to which Professor Desch replied on behalf of the guests. His Excellency Hjalmar Hammarskiöld, Governor of Uppsala, also honoured the

company with his presence at the lunch. While coffee was being served the old visitors' book containing the signatures of the members of the Institute who visited the works during the meeting of 1898 was produced, and was examined with much interest. After luncheon the mine, the source of the celebrated Dannemora ore, was visited, the arrival of the party being heralded by the firing of a number of blasting charges.

Dannemora Mines.

The mines are situated on the western shore of Lake Gruvsjön to the north of Uppsala. As the surface of the rock at the mines is about 7 metres below the surface of the lake and as this level was formerly considerably higher, there has been a constant danger to the mines from floods. By pumping and the building of embankments against the lake, and finally by ditching and endeavours to lower the level of the lake, this danger may now be regarded as overcome.

The Dannemora Mines are mentioned in writing for the first time in 1481, and were then worked for silver, probably in the sulphide dikes of the southern field. In 1532 the mines were worked for iron ore, which at that period was probably exported to Germany. In 1545 a large company, of which Gustavus Vasa was part-owner, was formed, and by that time the ore had probably begun to be smelted within the country, for in 1551 two blast-furnaces are mentioned, probably situated at Österby. Charles IX and Gustavus II Adolphus were both greatly interested in the development of the Dannemora Mines, which were to a large extent worked for the Crown. In 1627 the three ironworks belonging to the Crown—Leufsta, Österby, and Gimo—were leased to Louis de Geer, senior, and in 1643 these works were bought by him, which occasioned an extensive development in the mining industry in this part of the country. The present part-owners are only five, owing to concentration of the industry. These part-owners are: Gimo-Österby Bruks A.B., which includes the ironworks of Leufsta, Österby, and Gimo; Stora Kopparbergs Bergslags A.B., with the ironworks of Söderfors; Baron C. J. Beck-Friis for the Harg works; the Ljusne-Woxna A.B.; and A.B. Iggesunds Bruk, with the Iggesund and Strömbacka works.

The ore-bearing area at Dannemora has for long been divided into three fields: the northern field, the central field, and the southern field, to which should be added a less important parallel about 500 metres to the east. Of these fields the central field contains the purest as well as the richest ores, and it includes, apart from the regular central ore-body, also a western parallel, the Diamantgrufva, and Sveagrufva, which may be regarded as a dislocated continuation of the central ore field. The area of these three ore-bodies is about 10,000 square metres. The total area of all ore-bodies in the district is about 14,000 square metres. The central field ore-body has probably been worked since the middle of the sixteenth century. The method was by open quarrying, carried to a level of about 160 metres. In the middle of the 'seventies a level was arranged at 215 metres for overhead stoping with filling. This level was finished in 1919, but before that a new level had been arranged for shrinkage stoping at 260 metres, which is still worked. Preparations for a new level at 300 metres are now being carried on. The Diamond ore was found about 1908 at a level of 215 metres through diamond drilling in the central field. It was then approached at a level of 170 metres, and was worked upwards up to its outcrop. On the first level, 170 to 210 metres, the southern part of the ore-body has been extracted by shrinkage stoping, and in the other part it has been laid out for the underslicing method.

The Svea ore-body had also been struck at a deeper level, about 170 metres. On the first level, shrinkage stoping has been applied. On the second level slicing has been arranged for on account of the weak consistency of the ore. All the ore-bodies have a practically vertical dip, with only a slight pitch to the west. The broken rock from these mines is transported to the central shaft or Örners shaft, situated in the foot wall of the ore in the southern part. The transport is carried on by means of compressed air locomotives. On the surface the rock is crushed to the size of about 100 millimetres in a Blake crusher. It is transported by means of a belt conveyor to a magnetic separating works. Ore under 35 millimetres is separated for further concentration. From the magnetic separator the ore passes to a picking belt, where the highest grade is picked and poorer ore is rejected. The clean ore is then carried to a loading bridge or to a

reserve loading place close to the railway track by means of petrol-driven locomotives.

The northern field includes the Sjöhag, Fischer, and Roschets mines, and is worked by shrinkage stoping. The ore is hoisted through the northern shaft sunk to a depth of 300 metres. In the southern field the ore has been stoped out in open workings to a depth of 260 metres, and a level down to 300 metres has been excavated by shrinkage stoping. At present a second level, partly excavated, is arranged for slicing.

Power is now obtained from the Älvkarleby Power Station on the river Dalälven. About 500 kilowatts a year are used for the mining. The current obtained from the power station has a voltage of 20,000, and is transformed at the mines to 750 volts. Current of this voltage is used direct for pumps, compressors, and larger motors. The compressed air has a pressure of 7 atmospheres, and is led from the compressor to a hydraulic accumulator arranged in the mines at a depth of 72 metres. Its volume is 1600 cubic metres and the air is distributed from this storage room to the different lines. The hoisting engines are driven direct by compressed air, which is preheated to about 300° C.

The yearly production from the mines is estimated at 55,000 to 60,000 tons, of which 35,000 to 40,000 tons come from the central field. To this should be added the production of the concentrating works, about 15,000 tons. The concentrating works, which are combined with a coarse-separating works for ore larger than 50 millimetres, are magnetic, and produce fine-grained material of about 5 millimetres and fine concentrate.

According to analyses made in 1923, the unroasted ore of the Dannemora Mines averages 50 to 60 per cent. of iron, 1 to 2·70 per cent. of manganese, 0·003 to 0·005 per cent. of phosphorus, and 0·031 to 0·15 per cent. of sulphur.

The Dannemora Works.

The Dannemora Works, Dannemora—Gimo-Österby Bruks Aktiebolag—about 60 English miles due north of Stockholm, carry on the manufacture of iron and steel in the neighbourhood of the world-renowned Dannemora ore fields, of which they own the best mines.

The Dannemora Works—Österby, Leufsta, Gimo, &c.—were established around the Dannemora iron ore-fields as early as the sixteenth century. At first they were the property of the Swedish State, but in the seventeenth century they were sold to Louis de Geer, a rich Dutchman, whom Gustavus Adolphus the Great had persuaded to immigrate to Sweden. This de Geer, "the Father of Swedish Industry," introduced the Walloon forging method by bringing over to Sweden a number of Walloons, a race of skilful smiths, from the Ardennes, Belgium. Under his able direction the Dannemora Works soon became the leading ironworks in the country, and within a short time their products grew so renowned that England started to place important orders with the Dannemora Works, *e.g.* no less than 1500 cannon at a time, which was considered a big order in those times.

When Louis de Geer died, the different works were divided among his sons, and in the course of time some were sold to the families Grill, Tamm and Reuterskiöld. In 1876 the Tamm family formed the Österby Ironworks Company; in 1916 the fusion of the Gimo and Österby Works took place, and the Gimo-Österby Iron and Steel Works were formed, uniting again the old Dannemora Works, which had been partly separated for several centuries.

The principal raw material consists of the Dannemora ores, renowned over all the world on account of their freedom from phosphorus and other injurious impurities, and also on account of their exceedingly suitable content of slag-forming constituents. An interesting and important fact is that the Dannemora Works are the only ones in the whole world that are using the excellent Dannemora ores exclusively in their manufacture of various irons, steels, and steel articles.

The electric power driving the Österby Works is supplied by the Swedish State from the big water-power plant at Älvkarleby. The average power used per year amounts to 1200 to 1500 kilowatts. At Gimo the motive power is furnished by two steam turbine generators of together 200 kilowatts and mainly fired with blast-furnace gas. The Tobo works obtain their power from two blast-furnace gas-fired steam-turbine generators of 170 kilowatts together and from one steam engine of 75 b.h.p.

The motive power at Leufsta and Carlholm is furnished by water wheels and wood-fired steam boilers.

The company's chief iron and steel manufacturing industries are concentrated at Österby. The equipment consists of one blast-furnace, 54 feet high, with two Westman roasting furnaces, the yearly capacity being 7500 tons of pig-iron; a Walloon forging mill with six Walloon refining furnaces; one Lancashire refining furnace; one welding furnace and five steam hammers (one of 2, one of 1·5 and three of 0·5 tons each), the yearly capacity of the forge being 2000 tons of bar iron; two blister steel furnaces, with a yearly capacity of 600 tons of blister steel; two crucible steel furnaces, each with twenty-eight crucibles and having a yearly capacity of 2000 tons of crucible steel ingots; two electric furnaces of the Rennerfelt type of 1 and 0·6 tons respectively, with a yearly capacity of 2000 tons of ingots; two acid Siemens-Martin furnaces of 10 tons each, with a yearly capacity of 12,500 tons of steel ingots; an iron and steel foundry with one melting furnace of about 5 tons capacity per hour; rolling-mills with semi-finishing, finishing and merchant mills equipped with two reheating furnaces, eleven three-high mills, one three-high universal mill, one two-high mill and three cooling beds; a forge equipped with one hydraulic 500-ton forging press with the usual auxiliary plant; a saw-blade and machine-knife factory. All articles from the latter are of course made from Dannemora steel, one of the characteristics of this steel being that tools manufactured from it take an excellent and lasting cutting edge. The Österby saw blades and machine knives are, as a matter of fact, gaining such a high reputation for superior quality and are in such demand that it was decided last year to enlarge the saw-blade and machine-knife factory, which was established only in 1920. This enlargement of the factory will be finished in the autumn. Most of the factory buildings at Österby are of recent date, having been erected since 1918.

The Gimo Ironworks are equipped with two blast-furnaces, 53 feet high, three Westman roasting furnaces and one Greenawalt sintering plant, the yearly capacity being 17,000 tons of pig-iron.

The Tobo Ironworks comprise two blast-furnaces, 53 feet high, and three Westman roasting furnaces. Yearly capacity, 15,000 tons of pig-iron.

The Leufsta Walloon Works consist of four Walloon refining furnaces, two Walloon reheating furnaces, one welding furnace, one water-driven hammer, three steam-hammers and one helve hammer. The yearly capacity is 1500 tons of Walloon bar iron.

The Carlholm Lancashire Works contain six Lancashire refining furnaces, one helve hammer, three steam-hammers, two water-driven hammers, and one rolling-mill. Yearly capacity, 1500 tons of rough bars and 1000 tons of hammered Lancashire iron.

The Dannemora Works also carry on farming on a large scale. The total area of the company's landed estates amounts to 112,500 hectares (280,000 acres, or 440 square miles). Of this 13,500 hectares (33,000 acres) are tilled land or fenced pasturage, 83,000 hectares (208,000 acres) productive timber land, and 16,000 hectares (40,000 acres) other land.

At Gimo, Carlholm and Rånäs the company has erected saw-mills, and at Gimo also a tile-works.

The visit to the Gimo and Österby Works terminated at 4 P.M., and the party then entrained for Stockholm, which was reached about 7 in the evening.

Excursion II.

The special train for this excursion, like that for Excursion I., consisted of sleeping-cars of the most luxurious type, with a day-coach attached, and was used throughout the journey. The train was most courteously provided, free of charge, by the Swedish State Railways, and by the following private companies: the Nora Bergslags Railway, the Stockholm-Västerås-Bergslagens Railway, and the Bergslagernas Railway. No change of train occurred except at Karlstad on Tuesday morning, and the members returned at night to the original train at Finnshyttan.

Itinerary.

Sunday, August 29.

10.50 P.M.	Departure from Stockholm.

Monday, August 30.

8.50 A.M.	Arrival at Degerfors.
8.55 A.M.	Breakfast, by invitation of the Strömsnäs Steelworks.
9.30–11.20 A.M.	Visit to Steelworks.
11.25 A.M.	Departure from Degerfors.
12. 8 P.M.	Arrival at Bofors.

Monday, August 30 (cont.).

12.15 P.M.	Lunch, by invitation of the Bofors Co.
1.15–3 P.M.	Visit to the works.
3.2 P.M.	Departure from Bofors.
5.18 P.M.	Arrival at Hellefors.
5.20–7 P.M.	Visit to the works.
7.30 P.M.	Dinner, by invitation of the Hellefors Steelworks.
11. P.M.	Departure from Hellefors.

Tuesday, August 31.

1.38 A.M.	Arrival at Karlstad.
8. 6 A.M.	Departure from Karlstad (change of trains).
8.26 A.M.	Arrival at Skoghall.
8.30 A.M.	For the whole of this day the visitors were the guests of the Uddeholms A.B. The Skoghall Pulp Mill and the Hagfors Ironworks were visited, and the party were entertained to luncheon, and a dinner in the evening at Hagfors.
11.30 P.M.	Departure from Finnshyttan.
11.40 P.M.	Arrival at Filipstad.

Wednesday, September 1.

7.15 A.M.	Breakfast, by invitation of the Reception Committee
8 A.M.	Departure from Filipstad.
12.26 P.M.	Arrival at Fagersta.
12.30 P.M.	Lunch, by invitation of the Fagersta Steel Co.
1.45–3.40 P.M.	Visit to the works.
3.49 P.M.	Departure from Fagersta.
6.53 P.M.	Arrival in Stockholm.

At 10.50 P.M. on Sunday, August 29, the following members, thirty-nine in all, left Stockholm following the route planned for Excursion II.

Benedicks, Prof. Carl (Hon. Vice-President)
Bergsten, J.
Campbell, D. F.
Cohen, A.
Davies, W. R.
Gouge, P.
Hand, T. W.
Harbord, F. W. (Vice-President)
Heath, O. W.
Henderson, James (Member of Council)
Henderson, J. L. (junr.)
Hethey, G.
Holgate, T. E.
Julin, Alb. Lindsay von
Julin, J. Lindsay von
Kershaw, H. (Commercial Attaché, British Legation)
Lamberton, J. R.
Larke, Sir William (Director, Nat. Fed. of Iron and Steel Mfrs.)
Lloyd, Daniel C.
Lloyd, F. N. (junr.)
Lloyd, G. C. (Secretary)
Lyttelton, The Hon. R. G.
McCance, Dr. Andrew
McNaughton, J.
Moore, Dr. Harold
Olson, S. R.
Quijano, Ramon
Ridge, H. M.
Rylands, Sir Peter (President)
Sanderson, J. A.
Seaman, W. A.
Senior, E. W.
Senior, A. R.
Smeeton, J. A.
Ström, G.
Wahlberg, Axel (Chief Engineer, Jernkontoret)
Wahlfors, Wilhelm
Westman, E. B.
Wilkinson, W. H. (Cleckheaton)

The party travelled through the night to Degerfors, which was reached shortly before 9 A.M. on Monday. They were met by

Mr. Ernst Odelberg, Managing Director of the Strömsnäs Jernverks A.B., and Mr. G. E. Helling. On arrival they were entertained by the company to breakfast, and the visit to the Strömsnäs Works then proceeded in the company of Mr. Odelberg and Mr. Helling, and other members of the staff.

Strömsnäs Ironworks.

The Strömsnäs Ironworks date from about 1660, when Georg Camitz received a licence from the Board of Mines to establish a forge. This first plant stood at the lower part of the Falls of the Leth River, and was called Lower Degerfors. Six years later another forge was erected and was known as Upper Degerfors. Both works were owned by the Camitz family continuously for two hundred years, but in the middle of the nineteenth century the works changed hands several times. The first blast-furnace was started at Lower Degerfors in 1862, and was rapidly followed by six Lancashire forges and two rolling-mills. In 1871 a period of great activity set in and the plant was extensively developed. The company is part-owner of the ancient mining-field of Persberg, the ores from which form the foundation of the company's famous steel products. The company also obtains ore from Klacka-Lerberg, Striberg, Timansberg, Dalkarlsberg, Bergsäng, Tuolluvaara, and other famous ore fields. The power for the works is obtained from the fall of the Leth River with 9 metres head. All the rolling-mills are driven direct by turbines, but the auxiliary machines and other plant are electrically driven with current from the company's power station of 2000 horse-power. The steelworks now consist of two blast-furnaces, one acid and three basic Siemens-Martin furnaces, six rolling-mills, including one heavy plate mill and sheet mill, a spring factory and a nail factory, a machine shop, a foundry, and a shop for pressing heavy plates. The company also manufactures electric pig-iron at Trollhättan.

The Bofors Works.

Bofors was reached soon after midday. Here the party were received by Dr. Sven Winquist, Chairman of the Bofors Co., Mr. Helling and others, who at once conducted them through the

establishment. These works have a history dating from 1646. After 1873 great developments took place. A blast-furnace was built, followed by an open-hearth plant, and in 1884 machine shops for the manufacture of guns were established. In 1894 the well-known benefactor, Dr. Alfred Nobel, became the chief owner of the company, and under his management the Bofors Works made great progress. The company is chief part-owner in the mines of Striberg, Dalkarlsberg, Klacka-Lerberg, Timansberg, and Haggruvan. The ores for the most part are very low in phosphorus and sulphur, and have an iron content of from 53 to 67 per cent. Power for the works is generated in a hydro-electric power station on the company's own premises. Two water-turbines supply 3800 horse-power and two 300 horse-power Diesel motors of the company's own manufacture form a reserve in case of low water. A new power-station designed to supply 2000 horse-power is now being built at a waterfall about 2 kilometres distant from the works. For further extensions the company owns still another waterfall about 10 kilometres distant, where 8000 horse-power are available. The Bofors Works consist at present of the following departments: two blast-furnaces for charcoal pig-iron, with a total capacity of 15,000 tons yearly, three Siemens-Martin furnaces, a steel foundry, press forging shops, forging and drop stamping shop, hot rolling-mills, heat-treatment department, machine shops, and a range for testing guns, projectiles, armour plate, and powder. Tool steel and structural steel are also manufactured as well as various brands of alloy steel. The company owns a considerable area of forests, which supply wood for buildings and for charcoal burning.

After the inspection of the works the company entertained the members at luncheon, at which Mr. Winquist presided, who welcomed the guests in the customary hospitable Swedish fashion, and Sir Peter Rylands responded, expressing his thanks on behalf of the visitors.

Hellefors Ironworks.

The journey was resumed by the special train, Hellefors being reached about 5.30 P.M. Mr. T. Wigelius, Managing Director of the Hellefors Works, and Mr. Danielsen in company with Mr. C. H. Gille, Mr. E. Forsberg, and Mr. L. von Friesen, warmly

welcomed the party on arrival and led the way to the works, acting as guides to their guests. Industrial works were in existence at Hellefors several hundred years ago. In the sixteenth and seventeenth centuries silver ore was mined on the estate. The silver ores, however, being rather poor, the owners of the silver mines abandoned them and took to iron-making. In 1749 licences were granted for the erection of ironworks in three places in the neighbourhood of Hellefors. The steel industry of Hellefors is based entirely on charcoal and the pure iron ores from the well-known deposits of Sirsjöberg, Långban, and Persberg. The Hellefors company possesses about 345,000 acres of forests around Hellefors, from which the main supply of charcoal for the blast-furnaces at Sikfors and Säfvenfors is obtained. The annual output of these furnaces is about 16,000 tons of charcoal pig-iron. The old Hellefors steelworks were destroyed by a fire in 1918, and were re-erected upon an entirely new plan. The works are, therefore, quite modern, and may be regarded as one of the best equipped and best organised in Sweden for making high-grade steel.

The works at Hellefors consist of two open-hearth departments, with one basic and two acid open-hearth furnaces, and a cogging mill, medium mill, and wire rod mill, annealing department, laboratory, and a plant for the manufacture of hollow drill steel. An electric steel furnace of the Moore type is at present under construction. The capacity of the three rolling-mills is 20,000 to 25,000 tons of finished bars and rods per annum. The company is a large producer and distributor of electric power, about 15,000 k.v.a. being generated in its water-power stations. All the mills are electrically driven.

On the conclusion of the visit to the works the guests were conducted to Mr. Wigelius' mansion near by, where they were most hospitably entertained at dinner by Mr. and Mrs. Wigelius. Each guest found next to his plate a penknife of beautiful manufacture and finish made of the company's own special quality steel, for which each one present was called upon by the host to pay in accordance with the universal custom the sum of 1 öre. At the conclusion of a very delightful evening the party made their way to their special train by the light of an avenue of flares which had been placed, by the kindly forethought of the

host, along the private way to the railway station. They proceeded during the night to Karlstad, where the train halted for $6\frac{1}{2}$ hours.

The Uddeholms Company.

The next morning, Tuesday, August 31, the party arrived at Skoghall, on Lake Venern, where breakfast was at once served, the visitors being the guests of the Uddeholms Co. They were received by Mr. August Herlenius, Managing Director, Mr. Troili, Mr. Diedrichs, and Mr. Hellgren. Mr. Hellgren, the Manager of Skoghall, guided the party through the pulp mill.

At Skoghall there has been erected by the Uddeholms Co. one of the most modern wood-pulping mills. The present mill was built in 1914. It is electrically driven, and has, in addition to all the necessary auxiliary machines, twelve frames, four edgers, and two planers, with an annual output of about 24,000 standards of timber. A sulphite mill was erected in 1914, followed in 1919 by sulphate mills. The yearly production of the sulphite mill is about 28,000 tons of bleached and easy-bleached pulp, and that of the sulphate mill is about 35,000 tons of bleached, easy-bleached, and kraft. The by-products obtained in the manufacture of wood pulp are sulphite spirit, resin, turpentine, ether, &c., and the company owns besides large factories for making chloride of lime for its own requirements and for sale, caustic soda, and other chemical products.

After completing the tour of the pulp mills, the visitors took the train for Filipstad, which was reached about midday. On arrival Mr. Herlenius and his staff entertained the whole party to lunch.

The present Uddeholms Aktiebolaget was formed in 1870, having been taken over from the Geijer family, under whose ownership the works had been since 1720. The total area of the company's estates now aggregate over 700,000 acres of land, including large forests, iron ore mines, and an ample supply of water-power. Their four modern steel and tube works are connected mostly by their own railways, and they own a fleet of cargo steamers for the shipment of their products. The company is consequently to a great extent independent as regards all the more important necessities for their manufacture. The most important of the

company's ore fields are Taberg, Nordmark, and Finnmossen. Further, the company is the largest shareholder in the well-known Persberg mines. The total yearly output of the mines amounts to about 100,000 tons of high-grade iron ore. The Uddeholms Co. is also largely interested in the Tuolluvaara iron mines in Lapland. A large part of the natural water-power resources of the company have been harnessed, the total capacity of the hydro-electric stations amounting to about 50,000 horse-power. The Munkfors power station is now being built to produce a further 25,000 to 30,000 horse-power, and the falls not yet harnessed form a reserve calculated at about 40,000 horse-power. All the larger power stations are linked up, and supply power for the different works of the company, both for electro-chemical and mechanical purposes. Charcoal for the manufacture of steel is obtained from the company's own forest estate in Vermland. The iron ores from the company's own mines mentioned above contain 50 to 67 per cent. of iron with phosphorus from 0·002 to 0·010 per cent., and as the ores are smelted entirely with charcoal, the resulting pig-iron provides for the production of iron and steel of an extraordinarily high degree of purity, with phosphorus not exceeding 0·018, and sulphur below 0·015 per cent.

The Hagfors steelworks of the Uddeholms Co. is one of the largest and most modern steelworks in Sweden. It comprises five electric shaft furnaces, two ordinary blast-furnaces, and two electric furnaces for the manufacture of ferro-manganese. The steelworks consist of four open-hearth furnaces, two Bessemer converters, and one electric steel furnace, and the rolling-mill plant consists of a cogging mill, a universal mill, strip mills, merchant mills, wire and tool steel mills, other departments including a steam-hammer forge, a foundry, a machine shop and a screw factory. Charcoal and wood are the only fuels used for all the smelting and melting operations. By kind permission of the directors, the visitors were shown the Flodin experimental furnace used in the extensive trials carried out by the company with the aid of Jernkontoret in the manufacture of steel by the direct process, and the tapping of a 10-ton charge from the furnace was witnessed.

The Munkfors ironworks of the Uddeholms Co. specialise in

the manufacture of cold-rolled iron and steel, which are used for a variety of purposes, such as steel pens, razor blades, watch springs, aeroplanes, band saws, &c. The plant comprises two Siemens open-hearth furnaces, four Lancashire iron forges, and a large number of cold-rolling mills, five hot-rolling mills, steam-hammer forges for tool steel, a wire-drawing department, and another department for the manufacture of all kinds of railway waggon and carriage springs, and steel teeth for cultivators and other agricultural machinery. In these works again charcoal and wood are the only fuels used in all smelting and melting operations.

The Storfors Works were founded in the eighteenth century, and were converted into a private company in 1865. The majority of the shares was acquired by the Uddeholms Co. in 1908, and the remainder in 1918. The Storfors and Nykroppa tube and steel mills now consist of two blast-furnaces, three open-hearth furnaces, and a merchant iron and wire rod rolling plant; a large number of hot-rolling and cold-drawing tube mills are also installed. The chief speciality of Storfors is the manufacture of weldless boiler tubes, bicycle tubes, hydraulic tubes, tubes for motor-cars and aeroplanes, &c.

After completion of the tour of the works the visitors adjourned to the neighbouring hotel to dress, and the day finished with another delightful reception and dinner at which Mr. A. Herlenius presided, accompanied by his wife.

The party then returned to their special train, which remained throughout the night at Filipstad.

The Fagersta Steelworks.

On Wednesday, September 1, breakfast was served at 7.15 A.M. in the station restaurant at Filipstad, the members being the guests of the Reception Committee, and the train left shortly after 8 A.M., arriving at Fagersta about 12.30 P.M. The party were greeted by Mr. Axel Fornander, the Managing Director, and Mr. Ericsson, one of the Directors, and were conducted to the steel works. The works are situated in the iron district of Norberg, where iron-making has been carried on for many centuries. When it was first started at Fagersta is not exactly known, but it was probably about the end of the sixteenth century, as there is an ancient document bearing the date 1611 recording the privileges

of Fagersta as an ironworks. About 1850 the company acquired two old blast-furnaces, and erected a plate mill. In 1860 the Bessemer method was introduced. At present Fagersta has three blast-furnaces, which have been running since 1915, and this plant may be considered as the most modern in Sweden making charcoal pig-iron. The first open-hearth furnace was built in 1884; the Bessemer method was abolished in 1897, and the works now make exclusively open-hearth steel and crucible steel. During the years 1892 to 1903 J. A. Brinell was chief engineer in charge of the works, and in that period his method of hardness testing was devised, and worked out at Fagersta, his first testing machine being still preserved there. In 1907 Mr. Axel Wahlberg became manager of the works, and remained in that position until 1914, when he was appointed chief engineer of Jernkontoret. The equipment of the Fagersta works consists at present of the following: three charcoal blast-furnaces, with a total capacity of about 36,000 tons of pig-iron a year; six open-hearth furnaces, with a total capacity of about 60,000 tons of ingots; two electric steel furnaces for the production of high-speed steel, and other special steels. There are also two cogging mills, one universal mill, merchant mills, rod mills, and one plate mill. The forge contains one 1000-ton hydraulic press, eight steam hammers, two compressed-air hammers, and a drop hammer. The plant includes, besides a tube-drawing mill for cold-drawn steel tubes, a wire-drawing mill, a wire-rope factory, a factory for frame saws, circular saws, machine knives, planing tools, and spiral springs for railway carriages, a foundry and repair shop, and finally a saw-mill and planing shop for the timber from the works' own forests. Power for the works is obtained from the company's power stations with a total of 5500 horse-power. The company is sole owner of, or part-owner in, the following mines, Malmkärra, Stortägt, and other mines in the Norberg district, Tuolluvaara, Stripa, Bispberg, and others. The charcoal pig-iron obtained from the high-grade ores of the company's own mines is of even quality, and free from impurities. This material is the basis for the subsequent steel-making, and minute control is kept over the raw material and throughout the different operations up to the finished product. All material is tested chemically, metallographically, and mechanically in the modern works laboratory. After seeing all the departments of the

works, as well as the laboratory and museum, where Brinell's original testing machine is preserved and a number of the company's products are on view, the members were conducted to the manor-house, where they were entertained by Mr. A. Fornander and his associates to luncheon, and the party also included Mr. K. Huldt, who had come over specially from Kohlswa, and His Excellency Envoyé Lagercrantz, formerly Swedish Minister at Washington. Mr. Fornander bid the guests a hearty welcome, and Sir Peter Rylands, the President of the Institute, replied, expressing the thanks of the assembled guests. After luncheon the members of the party returned to their special train, which travelled on to Stockholm through the afternoon, arriving about 7 P.M.

Thus finished the most enjoyable and instructive three days' journey of the two groups of members who were privileged to visit some of the principal mines and ironworks in Central Sweden. It would be impossible to give adequate expression to the appreciation of the manner in which the guests were received and entertained, and the cordial thanks of the Institute, and especially of those who took part in the visits, are due to the kind hosts and hostesses who so hospitably received them at the various stages of their journey. In particular, the members on Excursion I. are indebted to Mr. Alf Grabe, and those on Excursion II. to Mr. Axel Wahlberg, for their unremitting devotion in attending to the smallest detail which might add to the pleasure, comfort, and convenience of the party, and for their entertaining companionship throughout the journey.

On Thursday evening, September 2, Sir Peter Rylands, President of the Institute, and a few other members still remaining in Stockholm, invited those who had so hospitably entertained them during the meeting to dine at the Grand Hotel. The guests present at this dinner were Mr. J. C. Kjellberg, President of Jernkontoret; Mr. Kinander, Director of Jernkontoret, and Mrs. Kinander; Mr. Allan Cederborg, President of the City Council of Stockholm; Mr. Axel Wahlberg, Chief Engineer of Jernkontoret, Mrs. Wahlberg and Mrs. Grabe; Mr. K. Huldt, President of the Swedish Society of Engineers and Architects; Professor C. Benedicks, Director of the Metallographic Institute, and Mrs.

Benedicks; Miss Carlander; and Mr. J. L. Dodds, Secretary of the British Legation. Mr. Grabe, who had acted as Hon. Secretary of the meeting, was unfortunately prevented by indisposition from being present. Sir Peter Rylands as President was in the Chair, and there were present besides: Mr. F. W. Harbord, Vice-President, and Miss Harbord; Mr. J. Henderson, Member of Council, Mrs. Henderson and Mr. J. L. Henderson, jun.; Sir William Larke, K.B.E.; Mr. H. B. Toy, Mrs. Toy, Miss M. Toy and Miss D. Toy; Mr. and Mrs. A. R. Banks; and Mr. G. C. Lloyd, Secretary, and Miss Lloyd. Mr. H. Brearley, Member of Council, also joined in the entertainment, but was unfortunately prevented at the last moment from attending. At the end of a very enjoyable evening, the British members bade farewell to their kind Swedish hosts with many regrets, and took their departure the following day for home.

OBITUARY.

Arthur Bakewell Baylis died at Whitby on August 22, 1926, at the age of seventy-five. In his nineteenth year Mr. Baylis joined the Midland Iron Co. Ltd., of Rotherham, as secretary, and was associated with that company for the remainder of his professional career, becoming eventually managing director, and Chairman of the Board. He was a recognised authority on the bar iron and kindred industries, and was chairman of the British Iron Manufacturers Association, the South Yorkshire Bar Iron Association, and the Hoop Manufacturers Association. He was elected a member of the Iron and Steel Institute in 1898.

Walter Dixon died on July 12, 1926. He was born in Hull in 1861, and on completion of his education he commenced his engineering career with Messrs. Amos and Smith, Ltd., of that city. He then joined the firm of Messrs. Richard Thornby & Sons, Ltd., Grantham, and was entrusted with the supervision of important contracts in London and other places. In 1891 he removed to Glasgow, where he became associated with Mr. M. B. Mountain, representative of Messrs. Ernest Scott and Mountain, Electrical Engineers, Newcastle, and he afterwards established himself in business under the name of Walter Dixon & Co., Electrical Contractors, Glasgow, and assisted the late Mr. James Riley in the development of the blast-furnace gas-engine. He carried out many important schemes for the electrification of iron and steel works, and was a pioneer in the introduction of three-phase alternating-current. About 1903 he gave up his contracting practice, and devoted himself to consulting work. Among Mr. Dixon's achievements in this connection may be mentioned the complete electrification of the works and mines of the Ebbw Vale Steel, Iron, and Coal Co., Ltd., to whom he acted as adviser for over twenty years. He was also responsible for the electrical equipment of the Rothesay Dock belonging to the Trustees of the Clyde Navigation. This was the first dock in Great Britain to be electrified completely, and the installation embodied many entirely new features. Mr. Dixon's interests were many and varied. He travelled largely, and apart from his business he was actively interested in numerous learned societies, to which he contributed many papers. He had been a president of the West of Scotland Iron and Steel Institute, and during his term of office in that capacity he took an active part in promoting research for the improvement of the puddling process. He was elected a member of the Iron and Steel Institute in 1897, and was a constant attendant at its meetings, frequently taking part in the discussions.

Christopher William James died at Hythe, Kent, on August 13, 1926. He was the son of the late Christopher James, consulting engineer of Bristol, whose family was closely identified with the early development of the iron and steel industry in South Wales. Mr. C. W. James was educated at Bristol and in Germany, and after an apprenticeship at Chesterfield he entered the service of Joshua Buckton & Co., Ltd., of Leeds. There he spent the whole of his professional life, becoming managing director and eventually chairman of the company, a position from which he retired in December 1925. Mr. James' most important professional work, in conjunction with the late Mr. Hartley Wicksteed, consisted in the design of tools for heavy gun and marine engine construction. He took an important part in developing testing machines for engineering materials, and of machine tools, the design of which was revolutionised by the introduction of high-speed steel. During the war Mr. James took a leading part in the organisation and management of the National Ordnance Factories in Leeds, and for some months in 1917 he was Director of Ammunition Production at the Admiralty. He was elected a member of the Iron and Steel Institute in 1901.

Harry Probyn died on August 20, 1926, at Edgbaston, at the age of sixty-five. He was the first secretary of the company of Guest, Keen & Co., and remained secretary when the company was re-formed under the name of Guest, Keen and Nettlefolds, Ltd. He resigned the secretaryship to become a director in 1918. He was elected a member of the Iron and Steel Institute in 1920.

Thomas Bond Rogerson died at his residence, Redcliffe, Bridge-of-Allan, on October 31, 1926, in his seventy-first year. He was born in Sunderland, and on completion of his education he served his apprenticeship as an engineer with the Weardale Iron and Steel Co. at Tow Law. He afterwards removed to Middlesbrough, where he entered the employment of the Linthorpe Ironworks, then under the management of the late Mr. Edward Williams (Past-President of the Iron and Steel Institute). In that position Mr. Rogerson acquired considerable metallurgical and mechanical experience, and was entrusted with the important work of the reconstruction of the Cyfarthfa blast-furnace plant in South Wales. Later he obtained the appointment of blast-furnace manager and steelworks engineer at the Leeds Ironworks of Messrs. Walter Scott & Co., Ltd. In 1892 he removed to Scotland, and took the position of blast-furnace manager at the Clyde Ironworks of Messrs. James Dunlop & Co., Ltd. The Calderbank Steelworks at Airdrie, belonging to the same company, also came under his charge in 1900, when he became general works manager, and later he became a director of the company. While in the service of Messrs. James Dunlop, Mr. Rogerson made frequent visits to the United States, and took charge

for a time of the blast-furnace plant of the Dayton Coal and Iron Co., Tennessee, of which company he was appointed a director. During his sojourn in the United States he made extensive journeys with the object of studying iron and steel works practice in that country. About 1923 he retired from active management of the Clyde Ironworks and the Calderbank Steelworks, but continued to give his services to his firm in a consultative capacity. He was a constant attendant at the meetings of the Institute, and contributed an important paper on the subject of briquetting iron ore, in collaboration with Mr. Guy Barrett. He was elected a member of the Institute in 1894.

John Bell Simpson died on April 26, 1926, at his home, Bradley Hall, Wylam-on-Tyne, at the age of eighty-nine. He was born at Ryton Woodside in 1839, and after serving his articles as mining engineer he became connected with the Stella Coal Co., Ltd., controlling several mines near Blaydon-on-Tyne. For many years Dr. Simpson was managing owner of the company, and was responsible for the great development of the collieries. He acted for the Crown in connection with mining properties, and was mining engineer to the Duke of Northumberland, Viscount Ridley, Viscount Allendale, Sir E. Blackett, and others. He also had charge of the Wallsend and Hebburn Collieries for some years, and later became associated with other important colliery companies in Durham. He became a director of several companies, including electric lighting companies in Newcastle, Cambridge, and Scarborough, Parsons' Marine Steam Turbine Co., and Hawthorne, Leslie & Co., Ltd. He was a past-president of the North of England Institute of Mining and Mechanical Engineers, and of the Institute of Mining Engineers. As the result of a series of lectures on geology delivered by him nearly sixty years ago, there was inaugurated a movement which resulted in the foundation of Armstrong College, Newcastle. Later Dr. Simpson contributed £10,000 towards the cost of founding the King Edward VII. School of Art at Armstrong College. He occupied a seat on the Council of the College, and in recognition of his work the University of Durham conferred on him the honorary degree of D.C.L. He befriended hospitals and similar institutions with the greatest generosity, and was a benefactor to various Associations for promoting the welfare of miners, in which he always took the greatest interest. Dr. Simpson was a member of the Institution of Civil Engineers, and a Fellow of the Royal Geographical Society. He was elected a member of the Iron and Steel Institute in 1877.

George James Valentine died at Workington on October 30, 1926, at the age of sixty-one. He held the position of research chemist in the employment of the United Steel Co. at Workington, and had been a member of the Workington Town Council since 1909. He was elected a member of the Iron and Steel Institute in 1903.

Sir John Roper Wright, Bart., died on July 25, 1926, at Widcombe Manor, near Bath, at the age of eighty-three. He was born in 1843 in Lancashire, and began his professional life as a premium pupil at the Soho Engineering Works, Preston. In 1865 he proceeded to Sheffield, where he became associated with the development of the Siemens furnace. Afterwards he went to Birmingham, where, under the direction of the late Sir William Siemens, he constructed the furnace which cast the first ingot made by the Siemens-Martin process. In 1867 Sir John Wright went to South Wales, and took over the management of the steel furnaces of the late Landore Siemens Steel Co. After a few years he left for Glasgow, but soon returned to Landore, and subsequently, in association with others, he joined the Panteg Steel Co. He shortly afterwards retired from that undertaking, and with Mr. Butler formed the firm of Wright, Butler & Co. They established the Elba Steelworks at Gowerton, and later acquired the Panteg Works, as well as the blast-furnaces and steel-melting plant of the old Landore Works and the Cwmavon Works. The firm of Wright, Butler & Co. was later absorbed by Baldwins, Ltd., Sir John Wright and his partners having seats on the Board. In 1920 he was created a baronet. He was elected a member of the Iron and Steel Institute in 1873.

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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The Editor has been assisted in the preparation of these Notes by R. Elsdon, Librarian of the Institute.

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—*GEOGRAPHICAL DISTRIBUTION OF ORES.*

(Arranged in alphabetical order under Countries.)

Alaska.—P. S. Smith, *Mineral Industry of Alaska in* 1924 (United States Geological Survey, 1926, Bulletin 783A). A summary is given of the results achieved during the year in the investigation of the mineral resources of Alaska, treating of the mineral deposits and of statistics of mineral production of the territory.

Australia.—*The Australian Mineral Industry* (Bulletin of the Imperial Institute, 1926, No. 2, vol. 24, pp. 318–333). A brief survey of the mineral industry of Australia is given.

Canada.—W. H. Collins, T. T. Quirke, and E. Thomson, *Michipicoten Iron Ranges* (Canada, Geological Survey, 1926, Memoir No. 147). A description is given of the iron ore deposits of the Michipicoten district, Ontario. Many analyses of ore samples are given.

A. H. A. Robinson, *Titaniferous Magnetite Deposits of Bourget Township, Chicoutimi District, Quebec* (Canada, Department of Mines, Mines Branch: Investigations of Mineral Resources and the Mining Industry, 1924, pp. 42–54). The geological features, some of the principal outcrops of titaniferous magnetite, nature of the ore, extent of the deposits, and economic possibilities are dealt with. Large deposits of titaniferous iron ore occur in this township. The ore is of two distinct types. One, the coarser-grained variety, contains a comparatively small amount of foreign matter disseminated through it in the form of dark-coloured, probably silicate, minerals. The other type is comparatively fine grained, compact, and tough; and is mixed with

very considerable amounts of other minerals. Analyses of the two grades are as follows:

	Coarse-Grained. Per Cent.	Fine-Grained. Per Cent.
FeO	36·91	25·39
Fe_2O_3	31·15	19·95
Al_2O_3	6·01	8·04
CaO	0·55	11·50
MgO	1·50	5·44
TiO_2	22·42	12·40
P_2O_5	0·925	9·810
S	0·007	0·038
SiO_2	1·00	6·80
CO_2	trace	trace

The deposits are confined to an area some 2000 feet long by 1200 feet wide. Mention is also made in the report of a process recently developed for the simultaneous production of a specially high-grade cement and pig-iron from titaniferous iron ores, in either the blast or the electric furnace. Titaniferous iron ore and limestone are smelted with either charcoal or coke, the products being pig iron, and a high-titanium slag which, after grinding, constitutes "titan" cement. The latter may be regarded as a fused Portland in which the bulk of the silica has been replaced by titanium dioxide.

G. A. Young, *Geology and Economic Minerals of Canada* (Canada, Geological Survey, 1926, Economic Geology Series, No. 1). This report consists of a general account of the geology and mineral resources of Canada. The minerals include cobalt, copper, iron, lead, zinc, magnesite, molybdenite, nickel, titanium, chromite, coal, manganese, petroleum, natural gas, oil shale, and tungsten.

J. E. Gill, *Gunflint Iron-Bearing Formation, Ontario* (Canada Geological Survey: Summary Report, 1924, Part C, pp. 28–88).

T. L. Tanton, *Eastern Part of Matawin Iron Range, Thunder Bay District, Ontario* (Canada Geological Survey: Summary Report, 1924, Part C, pp. 1–27).

Canada's Mineral Industry (Bulletin of the Imperial Institute, 1926, No. 1, vol. 24, pp. 94–106). A brief survey is given of the developments in the mineral industry of Canada.

Far East.—C. K. Leith, *Mineral Resources of the Far East* (Far Eastern Review: Foundry Trade Journal, Sept. 23, 1926, vol. 34, pp. 259–260). A review of the iron ore and coal resources of China, Japan, Netherland East Indies, India, and other countries.

India.—S. B. Banerjea, *Manganese and Bauxite in India* (Engineering and Mining Journal, Aug. 14, 1926, vol. 122, p. 254). A brief note on the production and export of manganese ores and bauxite from India, from the war period till to-day.

Morocco.—C. De Kalb, *Minas Del Rif and Moroccan Iron* (Mining and Metallurgy, Nov. 1925, vol. 6, pp. 563–564). Brief particulars are given of the iron ore deposit at Minas del Rif, about 14 miles south of Melilla. Minas del Rif is an isolated hill 3000 feet above sea-level. The outcrops are extensive, and although but partly explored they are known to cover an area about 10,000 by 7000 feet. The highest peak is pure hæmatite and magnetite, grey in colour from a film of lime deposited upon it. Only a beginning has been made at mining the main ore in place, but five quarries have been opened on one side of the mountain, and these reveal deposits of high-grade ore from 800 to 1000 feet in width. Analyses of the ore in place are as follows:

	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron	65·70	64·15	65·10	65·60	64·80
Silica	2·67	4·40	3·49	2·64	3·70
Sulphur	0·161	0·153	0·149	0·145	0·149
Phosphorus	0·018	0·023	0·020	0·022	0·023

Newfoundland.—O. R. Kuhn, *Wabana Ore from an Island of Iron* (Iron Age, May 6, 1926, vol. 117, pp. 1264–1266). The author describes the iron ore deposits on Bell Island, Newfoundland, the methods of mining, the character of the ore, and includes particulars of the quantity of ore available and the tonnage shipped during the past sixteen years.

Norway.—S. Foslie, *Mines and Ore Deposits of Southern Norway* (Norges Geologiske Undersoekelse, 1925, No. 126).

Russia.—P. P. Pyatnitzkil, *The Genetic Relations of the Deposits of Ore in the Krivoi Rog* (Transactions of Institute of Economic Mineralogy and Petrography, Moscow, 1924, No. 9, pp. 1–55). A treatise on the genesis of the iron ore deposits, including a description of the region and its geology, and the composition and structure of the crystalline rocks on the Dnieper. A comparison is made of the formations with those of the Lakes District of the United States. An English summary is included in the report.

Russia's Riches in Iron Ores (Mining Journal, July 24, 1926, vol. 154, p. 615). A brief note of an article in Deutsche Bergwerks Zeitung. Germany is increasingly using high-grade ores from Sweden and Spain in preference to the minette ores, and in the event of supplies being cut off by any country commanding the seas, there should be available the rich iron ore deposits in Russia which have been discovered in recent years north-east of the known ore field of Krivoi Rog in the so-called "Kurske Anomalie." It is estimated that these deposits contain about 630 million tons of iron reckoned as metal, distributed over a stretch of country 300 kilometres wide and at a maximum depth of 400 metres.

South Africa.—A. L. Hall, *The Manganese Deposits near Postmasburg, West of Kimberley* (Transactions of the Geological Society of South

Africa, 1926, vol. 29, p. 17). Important deposits of manganese ore were discovered about four years ago in the neighbourhood of Postmasburg, in the northern part of Cape Province. The bulk of the ore is psilomelane, in good physical condition for export. The ore is of the ferro grade, containing from 42 to 58 per cent. of manganese, 1·75 to 7 per cent. of silica, 3·25 to 10·9 per cent. of iron, and no phosphorus. Assuming an average thickness of 4 feet, there are approximately 900,000 tons of ore in sight. Along the outcrop of the deposit, where it passes under the Matsap beds, a further 1,800,000 tons are in sight, assuming an average thickness of 8 feet and an exploitation of over 10 feet on the dip.

South America.—R. Stappenbeck, *Mineral Resources of South America* (Mining Journal, Oct. 9, 1926, vol. 154, pp. 816–817). A condensed translation of a lecture to the German Economic Union for South and Central America, published in Metall und Erz. South America is comparatively poor in coal; the low-grade coals in some parts can, however, be economically utilised. The prospects for petroleum exploitation are, generally, more favourable than for coal-mining. The South American countries rich in iron ore deposits are Brazil, Chili, Peru, and Venezuela; the ore deposits in Minas Geraes, Brazil, are estimated at 2700 million tons; the Chilian deposit Algarrobal has ore reserves of about 200 million tons, and El Tofo about 100 million tons; the Peruvian hæmatite deposit Marcona is estimated to contain 500 million tons of ore. Large manganese ore deposits are worked in Chili, and Brazil is said to possess the world's largest manganese deposit near Corumba. Argentina and Bolivia are rich in tungsten ores, and Peru has the richest deposits of molybdenum and vanadium ores.

J. Daniels, *Iron Ores on the West Coast of Chile* (Mining and Metallurgy, May 1926, pp. 200–206). The principal iron ore deposits of Chile which are of immediate economic importance lie in a belt along the west coast, approximately 300 miles long, extending from a point near Taltal to south of Coquimbo. The ore-bodies are of considerable extent, and warrant careful exploration to determine their area and association with the rock. The ore consists of magnetite and hæmatite, hard and massive, and of high iron content. Some specular hæmatite is occasionally encountered, but is not characteristic of the main deposits. The author is of the opinion that the ores will be found ultimately to consist largely of magnetite rather than hæmatite. The Tofo deposit in depth is reported to be magnetite entirely, although on the surface some hæmatite is present. Little foreign matter such as silica accompanies the ore. Selected samples show the following range in analysis:

	Per Cent.
Iron	60·0 to 69·0
Silica	1·0 ,, 10·0
Phosphorus	0·003 ,, 0·210
Sulphur	0·01 ,, 0·08
Manganese	0·04 ,, 0·22

Particulars are also given of the activities of the blast-furnace plant at Corral, where experiments were conducted on the use of wood in the blast-furnace and subsequent by-product recovery. This plant has been out of operation during the last few years.

Sweden.—W. Petersson, *Notes on the Development of the Swedish Mining Industry during the Last Twenty-five Years* (Paper read before the Iron and Steel Institute, Aug. 1926 : this Journal, p. 95).

Trans-Caucasia.—J. V. W. Reynders, *Manganese Ore Deposits, Ltd.* (Iron Age, Sept. 30, 1926, vol. 118, pp. 924–925). In an address to the American Institute of Mining and Metallurgical Engineers the author summarises briefly the development in the Georgian manganese ore industry. An important concession has been recently granted to the United States.

United States.—M. C. Lake, *Future of Lake Superior Iron Ore Industry* (Paper read before the Associated Technical Societies, Cleveland, Ohio: Canadian Mining Journal, Sept. 3, 1926, vol. 47, pp. 866–867; Mining and Metallurgy, Aug. 1926, pp. 325–331). The distribution of the iron formation is known quite definitely in the Mesabi, Vermillion, Marquette, Menominee, and Gogebic districts. Its distribution is not so accurately defined in the Cuyuna, Iron River, and Crystal Falls, or Northern Wisconsin districts, where it is closely folded and hidden by a heavy covering of glacial drift. These areas in particular offer possibilities for the discovery of additional iron-formation areas which may contain high-grade ore-bodies. All the districts, except Mesabi, offer possibilities for the discovery of additional deposits of high-grade ore. The Mesabi district contains important tonnages of loose, sandy ores which are susceptible to methods of beneficiation at low cost. These ores can be mined by open pit methods, and the concentrates can be marketed in competition with the high-grade ores. At the present time the only beneficiation of iron ores in Michigan is by crushing and by hand-picking of rock and lean ore from the stock-piles. Several attempts have been made on a commercial scale to beneficiate Michigan and Wisconsin iron ores, but none of the plants is operating at the present time.

Value of Iron Ore (Iron Age, June 3, 1926, vol. 117, p. 1593). The Federal Trade Commission in its report recently issued declares that two companies control well over half of the iron ore resources of the United States. The present rate of production of iron ore in that country is about 75 million tons per annum. The world's production is about 170 million tons annually. At this rate the reserves in the United States would be mined out in somewhat over 100 years, unless other large reserves are discovered. There has been a continuous increase in estimates of the national ore reserve. In 1909 the total known reserve was estimated at from 4500 million tons, and in 1924 at

8000 million tons. This increase is apparently due in part to the inclusion of lower-grade deposits, and in part to the discovery of new deposits. The bulk of the high-grade ore is in the Lake District and is being mined out rapidly, and it is estimated that this reserve of 3000 million tons will be depleted in twenty or thirty years. The potential reserve of lower-grade ores eventually available probably exceeds 70,000 million tons.

Iron Ore Resources of the World.—O. R. Kuhn, *World's Iron Ore Resources now Exceed* 57,000,000,000 *Tons* (Engineering and Mining Journal, July 17, 1926, vol. 122, pp. 84–93). A broad and detailed survey of the more important iron ore resources of the world. In one table analyses of iron ores from various countries are given, and in a second table are detailed the iron ore reserves of the world, their mineralogical types and the approximate analysis of their principal constituents. (See also *Iron Ores of the World*, by the same author, Blast-Furnace and Steel Plant, Jan. 1926, vol. 14, pp. 2–12.)

Meteorites.—C. Palache, *Notes on New or Incompletely Described Meteorites in the Mineralogical Museum of Harvard University* (American Journal of Science, Aug. 1926, 5th Series, vol. 12, pp. 136–150). The new specimens dealt with are : A new pallasite from Ollague, Province of Potosi, Bolivia, and new iron meteorites from Sierra Sandon, Taltal, Chile ; from Britstown, Cape Province, South Africa ; from Cumpas, Sonora, Mexico ; from Mount Ouray, Chaffee Co., Colorado ; and from Gun Creek, Gila Co., Arizona. Additional notes are given of the following : the Colorado River Meteorite, and the Anderson or Prehistoric Pallasite.

II.—*PREPARATION OF ORES.*

Ore Concentration.—E. W. Davis, *Progress in the Beneficiation of Minnesota Iron Ores* (Mining and Metallurgy, July 1926, pp. 280–283). The American iron industry is in no immediate need of more merchantable ore. The reserves, however, are not inexhaustible, and the time when the high-grade ores will be depleted can be anticipated. Tremendous tonnages of high-silica ores are available, but no method has been perfected by which any considerable portion of this material can be utilised. Large quantities of low-silica concentrate have been produced by the washing process, but ores suitable for this process are becoming scarce. The jigging operation can only be used where there is a difference in specific gravity between the ore particles and the silica particles. The drying and sintering processes are only applicable to ores low in silicon, but high in moisture and ignition loss. An outline

is given of the experiments carried out at the School of Mines Experimental Station of the University of Minnesota in connection with the treatment of iron ores. Selective abrasion has been tried successfully for certain types of ores. Magnetic concentration has also been tried with satisfactory results. The ore is first crushed and passed through a roasting furnace and brought into contact with a reducing gas. The result is the removal of a small amount of oxygen from the iron oxide, which causes it to change from hæmatite to magnetite. The oxide may be concentrated magnetically at very small cost. Experiments have also been carried out to investigate the direct reduction process. The ore is reduced to sponge and passed over magnetic separators for the removal of a large portion of the silica. The product may be briquetted and melted down in an open-hearth furnace, and the remaining silica slagged off. The reactions of the process are described. Brief particulars are also given of the experimental work on the utilisation of high-silica manganiferous ores, and manganese extraction from low-silica manganese ores.

C. S. Parsons, *Concentration of Molybdenite Ore from the Moss Mine, Quyon, Quebec* (Canada Department of Mines, Mines Branch: Investigations in Ore Dressing and Metallurgy, 1924, pp. 68–71). The results are given of concentration tests of this ore. With proper manipulation a high-grade concentrate, 93 per cent. MoS_2, is obtained, with recoveries in excess of 95 per cent. of the molybdenite content of the ore. The concentrates are exceptionally free from deleterious substances, and are suitable for the manufacture of molybdic acid, molybdic salts, molybdenum metal, and ferro-molybdenum.

O. Lee, B. W. Gandrud, and F. D. De Vaney, *Magnetic Concentration of Flue-Dust in the Birmingham District* (United States Bureau of Mines, Report of Investigations, 1926, No. 2761). Flue-dust losses in the Birmingham district of Alabama average 250 lbs. per ton of pig-iron produced. The characteristics, composition, and screen size of the dust are tabulated. Tests show that the dust can be beneficiated if the hæmatite is properly reduced before it leaves the furnace. The non-uniformity of the flue-dust prevents the development of a single concentrating process to meet all requirements. Large scale tests were conducted with a dry magnetic separator for coarse ore, a wet magnetic cobbler for coarse ore, and wet magnetic log washer for finely crushed ore. The machines are described, and the results of the tests and flow sheets for each type are given. The relative merits of the wet and dry concentrators are also discussed.

K. Wolf, *Methods of Preparation of Minerals, in Particular the Flotation Process, and of the Purification of Clays and Kaolins by Electro-Osmosis* (Metall und Erz, 1925, vol. 22, pp. 474–480). The author reviews methods of mineral dressing, dividing them under the following four heads: mechanical wet methods depending on differences of specific gravity; electromagnetic methods utilising variations in magnetic properties; electrostatic methods involving the property of

electrical conductivity ; and flotation, in which physical and colloidal properties play a part.

Ore Roasting and Sintering.—J. Ruhrmann, *Research on the Desulphurisation of Spathic Iron Ore by Roasting* (Stahl und Eisen, Aug. 19, 1926, vol. 46, pp. 1118–1119). Tests were made on a large scale with carbonate ores containing up to about 3·5 per cent. sulphur, in a kiln of 4·3 metres diameter and 6·1 metres in height. The size of the ore was of considerable influence on the degree to which desulphurisation could be carried. With lumps of over 70 millimetres the sulphur was reduced only by 10 per cent. ; with lumps of less than 70 millimetres the reduction amounted to 47 per cent. A considerable reduction in the sulphur occurred by heating the ore and quenching suddenly in cold water. Steeping the ore in water for some hours was also effectual in removing a large proportion of the sulphur.

E. Greulich, *The Magnetisability of the Roast Products obtained on Heating Magnetite in Contact with Air, in Relation to their Chemical Composition* (Glückauf, Oct. 2, 1926, vol. 62, pp. 1297–1305). Samples of magnetite were heated in the air at temperatures ranging from 400° to 1550° C. The magnetisability of the roast throughout the whole temperature range was found to be dependent on the content of Fe_3O_4, but a strict proportionality between the magnetisability and Fe_3O_4 content does not exist; the relation is sufficiently regular, however, to show the value of the results in their application to ore-dressing technique. For example, by determining chemically the Fe_3O_4 content, it can be readily determined whether an ore can be successfully treated by magnetic concentration.

L. Rocaut, *The Agglomeration of Minerals Brought to the Works at Třinec* (*Czechoslovakia*) (Revue de Métallurgie, Mémoires, May 1926, vol. 23, pp. 292–294). The plant consists of two rotary kilns fired with pulverised fuel, each producing 200 tons of agglomerated material daily. The material treated consists of dust from calcined minerals, Swedish concentrates, and pyrites. The manner of treatment, and the plant in which it is carried out, are described.

R. Wallace, *Coke-Burning Ignition Stoves for Sintering Machines* (Engineering and Mining Journal, Sept. 11, 1926, vol. 122, p. 412). An illustrated description of a coke-burning ignition stove for use with a Dwight-Lloyd sintering machine. It gives better results than the oil or coal-dust-burning stoves which the Midvale plant of the United States Smelting, Refining and Mining Co. had previously been using.

REFRACTORY MATERIALS.

Kaolin in Silesia.—E. Pralle, *The Kaolin Deposits of Silesia* (Abhandlungen zur praktischen Geologie und Bergwirtschaftlehre, 1926, vol. 7, 52 pp.). A description of the origin and geological conditions of the kaolin deposits which occur extensively in Silesia. Chemical analyses of the clays found in the principal deposits are given.

Preparation, Properties, and Tests of Refractories.—M. C. Booze, *Importance of Refractory Tests* (Fuels and Furnaces, 1926, vol. 4; Feb., pp. 175–178; Mar., pp. 281–285; Apr., pp. 425–430). It is pointed out that the more important properties of a refractory material can be determined by the following tests: (1) Chemical analysis, (2) Softening point, (3) Spalling, (4) Deformation under load, (5) Slagging, and (6) Contraction or expansion. The different tests are described by the author.

M. C. Booze, *Specifications for Refractories* (Fuels and Furnaces, May 1926, vol. 4, pp. 553–556). The limitations of specifications for refractory materials are indicated.

A. J. Dale, *The Testing of Refractory Material for Resistance to Slag Corrosion and Erosion* (Paper read before the Institution of Gas Engineers: Iron and Coal Trades Review, Sept. 24, 1926, vol. 113, p. 463).

A. Grounds, *The Testing of Refractory Materials* (Fuel Economist, Feb. 1926, vol. 1, pp. 219–222). An illustrated description is given of the Atom testing machine, which can be used for determining the softening points of refractory materials. By means of automatic mechanism, it can also be made to record graphically the thermal expansion before the softening point is reached, and the subsequent contraction.

G. E. Merritt, *The Thermal Expansion of Some Fused Oxides used as Refractories* (Paper read before the American Electrochemical Society, Oct. 1926). The oxides considered are those of silicon, zirconium, thorium, and a mixture of the oxides of thorium and zirconium. The expansion of refractories made of magnesia and alumina were also measured. The results are presented in the form of graphs.

A. E. MacGee, *The Rôle of Specific Heat in the Selection of Refractories* (Journal of the American Ceramic Society, June 1926, vol. 9, pp. 370–373). A brief discussion of specific heat in which consideration is given to its determination at high temperatures, the methods which have been used in the past for its determination, and the application of

the values in the selection of refractories. The need of determining physical properties of bricks which have been in service is pointed out.

H. Spurrier, *Continuity in Plastic Bodies* (Journal of the American Ceramic Society, Aug. 1926, vol. 4, pp. 535–540). The physics and chemistry of making clay plastic are discussed.

M. C. Booze, *The Use of Refractory Cements and Plastic Refractories* (Fuels and Furnaces, June 1926, vol. 4, pp. 677–678).

F. A. J. Fitzgerald, *An Application of Recrystallised Silicon Carbide* (Paper read before the American Electrochemical Society, Oct. 1926). The use of recrystallised silicon carbide as a refractory material is briefly described.

Fireclay Brick: Their Manufacture. Properties, Uses, and Specifications (United States Bureau of Standards, 1926, Circular 282). The report opens with a brief historical account of the manufacture of fireclay brick, and the growth of the industry in the United States. It contains essential information regarding the manufacture of fireclay brick, the classification, properties, and uses of the finished product, and a brief discussion of the geology of the raw materials, their classification, and the characteristic properties of each class. The history of the development of the United States Government Master Specification for Fireclay Brick, together with a list of the principal references to literature on the subject, is also included.

Report of Committee C–8 on Refractories (American Society for Testing Materials, June 1926). The Committee submits revisions of methods of testing fireclay brick, and of the standard definitions of clay refractories. An industrial survey is given of refractories suitable for open-hearth furnaces and for the copper and zinc industry. The spalling test for fireclay brick is also discussed.

E. R. Thews, *Fireclay Bricks* (Foundry Trade Journal, Apr. 29, 1926, vol. 33, pp. 339–341). A discussion of the properties of fireclay bricks and their requirements for metallurgical furnaces. Of all the refractories commonly used, fireclay bricks are least subject to change of volume and shape under actual working conditions. Well-burned fireclay bricks of good quality are subject only to the normal coefficient of expansion amounting to $0 \cdot 59 \times 10^{-5}$.

A. E. R. Westman and W. H. Pfeiffer, *A Comparison of the Uniformity of Strength and Texture of Firebrick made by Different Processes* (Journal of the American Ceramic Society, Sept. 1926, vol. 9, pp. 626–632). An analysis is presented of data on the transverse strength and permeability of a number of brands of firebrick, and a comparison is made of the relative uniformity of strength and texture of the bricks made by different processes. Of the brands examined, those made by the stiff-mud process were found to be more uniform in strength and less uniform in structure than those made by the dry-press process. The hand-made bricks showed quite a variation in both strength and texture, whereas one brand of brick made by a semi-dry process (English type machine) showed good uniformity in both strength and texture.

L. C. Hewitt, *Fusion Points of Firebrick Coal-Ash Mixtures* (Journal of the American Ceramic Society, Sept. 1926, vol. 9, pp. 575–582). Six types of refractory brick were tested with five types of coal-ash, the cone fusion points of the brick-ash mixtures being determined over a range of 10 per cent. brick, 90 per cent. ash, to 40 per cent. brick, 60 per cent. ash. Sintered mixtures of refractory and ash tended to give higher fusion points than the raw mixtures.

R. F. Geller and W. L. Pendergast, *Comparative Tests of Some American and German Fireclay Brick* (Journal of the American Ceramic Society, June 1926, vol. 9, pp. 370–373). The results are given of tests carried out by the Bureau of Standards on German and American fireclay bricks. Chemical analysis, determination of softening points, standard load test for high-duty brick, quenching test and endurance test, were carried out. The results indicate that the German bricks are so slightly lower in quality that they can be considered as practically the equal of the American bricks.

F. H. Norton, *The Mechanism of Spalling* (Journal of the American Ceramic Society, July 1926, vol. 9, pp. 446–461). The author has made a study of the stresses and fractures developed in a solid when rapidly heated or cooled. The stresses were measured in bakelite specimens by the photoelastic method. High stresses in all cases were found to occur near the surface of the solids, but no high-tension stresses were present when the specimens were being heated. A number of vitreous clay spheres and bricks were heated and cooled rapidly, and the nature of the cracks was noted. In practically every case the fractures occurred as predicted from the measured stresses. Torque-deflection curves were obtained for a number of firebricks in torsion at different temperatures. The temperature at which plastic flow occurred for every material tested was approximately the same as the temperature at which the initial deflection under compressive loads in a standard load test took place.

F. W. Preston, *The Spalling of Bricks* (Journal of the American Ceramic Society, Oct. 1926, vol. 9, pp. 654–658). Spalling occurs as a tensile and not as a shear fracture. The surface of separation bears no simple relation to the isothermal surfaces. In a "semi-infinite" slab the diffusivity has no influence on the tendency to spall, but does influence the location of the surface of parting.

W. E. S. Turner, *The Attack of Arsenic Compounds on Fireclay Refractory Materials* (Journal of the American Ceramic Society, July 1926, vol. 9, pp. 412–422).

J. W. Fagan and F. West, *Practical Results and Experience in the Drying and Burning of Refractory Materials* (Paper read before the Ceramic Society, Sept. 1926). The paper describes a drying floor, a tunnel dryer, and its connections for obtaining and distributing heat, kilns for burning refractories, and various subsidiary contrivances in use at the Friden Works. The tunnel dryer at the outset was direct-fired, but this system was superseded by the Uzallete system of using

waste heat from kilns. The two types of kilns in use are the semi-continuous down-draft and down-draft beehive types. Practical results obtained with the plant are given. An account is also given of trials carried out on the oil-firing of the semi-continuous kilns.

C. E. Moore, *Some Changes taking place in the Low-Temperature Burning of Stourbridge Fireclay* (Transactions of the Ceramic Society, Session 1925–26, vol. 25, Part 2, pp. 127–149).

S. R. Hind, *Tunnel Kilns for Burning Firebricks* (Transactions of the Ceramic Society, Session 1925–26, vol. 25, pp. 154–170). The requirements of a tunnel kiln for the burning of firebricks are discussed, and its value to British firebrick manufacture is surveyed.

H. Hälbig, *A Modern Lime Kiln* (Stahl und Eisen, Aug. 19, 1926, vol. 46, pp. 1119–1121). A lime kiln of modern type with all accessories is illustrated and described. It is heated with producer-gas, and the output is about 75 tons of burnt lime, with a fuel consumption of 10 to 11 tons of coal, or 7 to 8 per cent. of the weight of limestone charged.

J. Bronn, *Fused Magnesite* (Metall und Erz, 1926, No. 4; Iron and Coal Trades Review, Apr. 30, 1926, vol. 112, p. 744). A discussion of the properties of fused magnesite, a material of considerable importance as a refractory for use in high-temperature melting furnaces. Ruff in 1913 established that the fusion temperature of CaO was above 2450° C., and that of MgO above 2550° C. Kanolt determined the fusion temperatures of the two oxides at 2570° C. for CaO, and 2820° C. for MgO. Based on the results of work by different investigators, the author has plotted a diagram in which the four oxides, SiO_2, Al_2O_3, CaO, and MgO, are arranged according to their fusion temperatures. The curves between the verticals correspond to the fusion temperatures of all intermediate mixtures of each pair of oxides in molecular relation. The diagram relates to mixtures in very finely powdered form and thoroughly mixed. The influence of SiO_2 and Al_2O_3 in admixture with MgO is also shown. For certain purposes it appears to be of importance that fused magnesite shall not take up carbon dioxide from the air. Experience has shown that this material exposed for two years in the open air had not developed the slightest change in its smooth and lustrous surface.

A. I. Andrews, G. A. Bole, and J. R. Withrow, *The Making of Dolomite Brick and a Study of their Properties* (Ohio State University, University Studies vol. 2, No. 3: Engineering Experiment Station, 1925, No. 30, pp. 7–51).

W. J. Rees, *Influence of Iron Oxide in Promoting the Inversion of Silica* (Paper read before the Ceramic Society, Sept. 1926). It is evident from observations that the presence of iron oxide in a silica-brick batch effects, at normal silica-brick kiln temperatures, not simply a greater degree of quartz inversion, but also an acceleration of the rate of tridymite formation. It appears possible that the presence of 2 to 2·5 per cent. of iron oxide in silica bricks for use in open-hearth or other metallurgical furnaces would be advantageous, as the increased tridymite

content of the bricks would result in greater volume stability and reduced spalling tendency. For coke-oven bricks it is probable that the advantages of greater tridymite formation would be offset by the effect of the iron oxide in promoting cracking of carbon monoxide and internal deposition of carbon in the bricks.

J. F. L. Wood, H. S. Houldsworth, and J. W. Cobb, *The Influence of Foreign Matter on the Thermal Expansion and Transformation of Silica* (Paper read before the Ceramic Society, Sept. 1926). Quartzite flour composed of 97·6 per cent. silica, 1·4 per cent. ferric oxide, and small amounts of other substances, was used in the tests. Measurements were made of the reversible thermal expansion, and the specific gravity, porosity, and refractoriness were determined. For mixing with the quartz, twenty-eight different substances were used separately, 2 per cent. being added in most cases, and test-pieces were fired at cones 9, 12, and 14. It was found that boric acid, potassium carbonate, potassium chloride, potassium chromate, biotite, sodium felspar, lithium chloride, ferric oxide, and borocalcite facilitated the conversion of the quartz. The specific gravity did not in all cases give an accurate indication as to the reversible thermal expansion.

W. Souder and P. Hidnert, *Measurements of the Thermal Expansion of Fused Silica* (United States Bureau of Standards, 1926, Scientific Paper 524). The paper gives the results of an investigation on the thermal expansion of transparent and non-transparent fused silica for various temperature ranges between −125° and +1000° C. A detailed description of the apparatus, the methods used in the investigation, and a summary of available data obtained by previous observers, are given. A critical temperature or minimum length was found at about −80° C. Expansion occurred on heating fused silica above the critical temperature, or cooling below this temperature. The coefficients of expansion of the transparent samples differed slightly from the coefficients of the non-transparent samples. Typical expansion curves are shown and discussed. A table is included which gives a résumé of average coefficients of expansion derived from the data on all samples for various temperature ranges between 20° and 1000° C.

A. T. Green, *The Effect of Industrial Usage on the Thermal Conductivity of a Semi-Silica Material Used in a Coke-Oven Wall* (Paper read before the Institution of Gas Engineers, Sept. 1926: Gas World, Coking Section, Oct. 2, 1926, vol. 85, pp. 111–112). The author has been able to obtain a sample of a semi-silica material which had been a constituent part of a coke-oven wall for eighteen years, together with a sample of the original unused material. He presents the results of the determination of the thermal conductivities and of other properties of the two samples, and discusses the changes in these properties and in the appearance of the "used" specimen.

A. T. Green, *A Comparison of the Temperature Diffusivities and Thermal Conductivities of Silica and Fireclay Refractories* (Paper read before the Institution of Gas Engineers, Sept. 1926: Gas World,

Coking Section, Oct. 2, 1926, vol. 85, pp. 112–114). The diffusivities of fireclay materials are generally lower than those of silica products both at lower and higher temperatures, but the variation is very wide, and there are many cases where the reverse is true. The apparent specific gravity of a well-fired silica brick is much less than that of a fireclay brick, and this tends to give lower values for the coefficient of thermal conductivity of silica products. Most silica bricks are better conductors than fireclay bricks at 1200° C., though at 800° C. they generally appear to be about equal in this respect, only the superior well-fired silica bricks showing greater conductivity. Poorly burned silica bricks are comparatively poor conductors. Silica bricks in general show a greater increase of diffusivity and thermal conductivity with rise of temperature than firebricks. Low porosity is not necessarily an indication of good heat conduction.

S. M. Phelps, *A Study of the Shrinkage of Diaspor Clays* (Journal of the American Ceramic Society, Oct. 1926, vol. 9, pp. 659–666). The mechanism of firing shrinkage was studied, and the effect of particle size, time, and temperature upon the shrinkage of diaspor clays of various compositions is described. The shrinkage under different conditions of time and temperature is inverse to the order of alumina content.

A. J. Dale, *An Investigation of the Premature Failure of Combustion Chamber Material* (Paper read before the Institution of Gas Engineers, Sept. 1926: Gas Journal, Sept. 29, 1926, vol. 175, pp. 862–865). A report of a research conducted by the British Refractories Research Association. The refractory contained a silica content of 88 per cent. and a considerable amount of free quartz, and it is suggested that such fine-grained, friable material needed special care during the preliminary heating up.

S. S. Cole, *Requirements of Refractories for Manufactured Gas Plants* (Journal of the American Ceramic Society, July 1926, vol. 9, pp. 462–473). The requirements of the refractories used in gas-producers, water-gas sets, horizontal and vertical retorts, and gas- and coke-ovens are discussed, with respect to the specifications which the material must meet to prevent failure of the installations. Illustrations show various types of installations and details of certain refractory shapes employed.

E. J. Brady, *Specifications for Lining and Checker Brick for Water-Gas Manufacture* (Journal of the American Ceramic Society, Oct. 1926, vol. 9, pp. 667–678). Specifications are given for all refractories used in water-gas manufacturing plants.

W. T. Gardner, *Refractories in the Gas Industry* (Paper read before the Ceramic Society, Sept. 1926). A critical discussion of some of ths outstanding features of various types of refractories used in the gae industry. The subjects dealt with include the characteristic features of fireclay refractories, siliceous refractories, and silica refractories.

L. Litinsky, *Refractory Materials for Coke-Ovens and Gasworks Retorts* (Pamphlet, 8vo, 50 pp. Halle, 1926. W. Knapp). A general

description is given of the composition, properties, and preparation of silica and fireclay, and their use in the manufacture of bricks for the construction of coke-ovens and gas retorts, with notes on their durability and resistance to attack by salts.

E. B. Powell, *Boiler Furnace Refractories* (Transactions of the American Society of Mechanical Engineers, 1925, vol. 47, pp. 839–930). Improvement in refractories does not appear to have kept pace with the advances made in combustion equipment, and water-cooling is employed to overcome some of their limitations. Fireclay brick is specially dealt with, and some of the limitations of refractory raw materials, current practice and improvements in manufacture, service conditions in the boilers, characteristics of commercial refractories and analytical tests, are discussed. Besides the necessity for further study, there is a need for a means to be devised for the interpretation of laboratory tests in terms of service performance. It is believed that the microscope will prove of material assistance in this study.

V. Weinod, *Relining Smelting Furnaces* (Metal Industry, Sept. 17, 1926, vol. 29, pp. 273–274). A few notes on the repair of furnaces, the destructive agents which the brickwork must withstand, and the design of the structure of the furnace.

M. C. Booze, *Refractories for Use in Steel Plants* (Paper read before the Association of Iron and Steel Electrical Engineers, June 1926). A discussion of the problems connected with the use of refractories in iron and steel works.

F. W. Schroeder and B. M. Larsen, *Progress Report on the Effect of the Open-Hearth Process on Refractories* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). This paper gives results of investigations undertaken by the Bureau of Mines and the Carnegie Institute of Technology to determine service conditions of open-hearth refractories. Information is given as to the source, composition, and effects on refractories of dusts and fumes given off from the charge and the molten bath in open-hearth furnaces under various conditions. Apparatus, methods, and results of sampling furnace gases are described. The factors governing the reaction of silica brick to oxide dusts, and the causes tending to produce corrosion in different parts of the furnace, are discussed, with special attention to fusion, spalling, and hole formation in the roof arch, and to dust deposits in checker chambers and tunnels.

F. W. Schroeder and B. M. Larsen, *Open-Hearth Steel Furnace Conditions as they Affect Refractories* (Paper read before the American Refractories Institute, May 12, 1926 : Fuels and Furnaces, June 1926, vol. 4, pp. 705–706). Service conditions which cause the failure of refractories in the open-hearth furnace are usually classified as follows : (1) excessive temperature, (2) temperature fluctuations, (3) slag corrosion, (4) excessive load, and (5) abrasion.

Service Conditions of Refractories for Open-Hearth Steel Furnaces (Carnegie Institute of Technology, Bulletin No. 23 of Mining and

Metallurgical Investigations: Foundry Trade Journal, June 17, 1926, vol. 33, p. 468). The results are presented of a study of the conditions of service which affect the use and wear of refractory materials used in the construction of open-hearth furnaces.

Interlocking Roof Tile (Iron Age, Sept. 9, 1926, vol. 118, p. 709). Particulars are given of an interlocking roof tile for open-hearth furnaces. Interlocking is accomplished by the use of a triangular tongue on one face and a groove on the other face of the tile. The life of the roof may be lengthened by the use of these tiles.

H. V. Grundy and A. Phillips, *Refractories in the Foundry* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1926, vol. 33; June 3, pp. 387–391; June 17, pp. 445–448). A discussion of the methods of testing and characteristics of moulding sands, blackings, and facings. The properties of firebricks used in cupola construction and the action of slag on cupola linings are also dealt with.

M. C. Booze, *Foundry Refractories* (Fuels and Furnaces, Sept. 1926, vol. 4, pp. 1071–1076). A discussion of conditions imposed on refractories in foundry furnaces. Abrasion, flame impingement and expansion, wall construction, specifications, and methods of testing are dealt with.

L. Jordan, A. A. Peterson, and L. H. Phelps, *Refractories for Melting Pure Metals: Iron, Nickel, Platinum* (Paper read before the American Electrochemical Society, Oct. 1926). The Bureau of Standards has carried out an investigation of the refractory materials best suited for the melting of pure iron, nickel, and the platinum metals. Pure magnesia crucibles are suitable for pure iron and iron alloys, but usually the magnesia crucibles contain too much sulphur, which is readily absorbed by the iron. Zircon added to the magnesia greatly increases the strength of the crucibles, but the zircon should be low in phosphorus. Pure iron melted in zirconia crucibles was found to have taken up large amounts of silicon. Crucibles made of "R.R. Alundum" contaminated the iron by as much as 0·07 per cent. silicon. Crucibles made of chemically pure MgO with $MgCl_2$ as a binder proved to be most satisfactory for pure iron and iron alloys.

M. Unger, *Refractories for Induction Furnaces* (Paper read before the American Electrochemical Society, Oct. 1926). The requisites for a commercial furnace lining for induction furnaces are detailed and discussed. Of the various materials studied, magnesium oxide proved to be the best. Proper grading of the magnesium oxide is very important. Pitch was found to be the best bonding material. For continuous operation with steel and a slag analysing 20 to 25 per cent. of silica, the magnesium oxide lining will last about 400 heats.

R. Walker, *New Furnace Lining* (Iron Age, Aug. 12, 1926, vol. 118, p. 420). The application of monolithic lining to an oil-fired annealing furnace is described.

M. L. Hartmann and O. B. Westmont, *Thermal Insulation of Electric*

Furnaces (Paper read before the American Electrochemical Society, Oct. 1926). The thermal insulation of various types of electric furnaces is discussed. The thermal conductivities of fused alumina, fused magnesia, fireclay, and a high-temperature insulating refractory are given, in addition to the published data on silicon carbide (carborundum) and silica. Mean specific heat curves for these refractories are also given. The external temperatures, heat losses, and heat capacities of thirteen types of electric furnace linings are tabulated, with the inside surface temperatures assumed to be 1600°, 1400°, and 1200° C. The object of the paper is to suggest possibilities of energy conservation in electric furnaces by properly designed composite walls.

M. H. Mawhinney, *Selection of Proper Furnace Insulation* (Forging, Stamping, Heat Treating, Sept. 1926, vol. 12, pp. 328–333). The author discusses the selection of proper insulating material for the various conditions which commonly occur in practice. Each case must be considered as a separate problem, because the correct insulation for one temperature and fuel is by no means correct for other conditions. The economic side of the question is also dealt with, for the insulation must pay for itself by the economies in fuel which it effects ; if it does not, then nothing is gained by its use.

FUEL.

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I.—*CALORIFIC VALUE.*

Calorific Value of Fuel.—A. de Zawaritzky, *Graphical Method for the Determination of the Calorific Power of Coal* (Chaleur et Industrie, Apr. 1926, vol. 7, pp. 191–199). The author has drawn up a series of graphical charts based on Goutal's formula for the calculation of the calorific power of coal, and gives two examples illustrating their use.

Rules for Employing the Results of Thermal Control Tests (Chaleur et Industrie, Aug. 1926, vol. 7, pp. 429–433). The article shows how to calculate the calorific power, the volume of air necessary for combustion of the fuel, the heat lost by incomplete combustion and in the waste gases, and other useful information from the analyses of the fuel and of the flue gases.

Nielsen, *A Simple Gas Calorimeter* (Chaleur et Industrie, June 1926, vol. 7, pp. 316–318). The article describes a simple calorimeter for making determinations on gaseous fuels.

A. Sauermann, *Influence of the Variable Composition of Coke-Oven Gas on its Fuel Value* (Glückauf, Oct. 9, 1926, vol. 62, pp. 1333–1340).

Combustion of Fuel.—W. Gumz, *The Temperature of Combustion and its Graphical Representation* (Feuerungstechnik, Feb. 1926, vol. 14, pp. 109–112). The construction of a chart, from which the theoretical temperature attainable can be read off when the calorific power of the fuel and the proportion of excess air is known, is described. The actual temperature of combustion is dependent on many factors, and many assumptions are made in arriving at the formula given. It may be seen, however, that despite the use of preheated air and of rapid rates of burning, the temperature of combustion remains sensibly constant, and this becomes of importance in indicating the maximum that may be expected from a firebox or furnace.

M. Bouffart, *An Essential Principle for the Scientific Conduct of Industrial Combustion* (Chaleur et Industrie, Aug. 1926, vol. 7, pp. 437–

442; Revue Universelle des Mines, Aug. 1, 1926, vol. 11, pp. 123–136). The author shows how the carbon monoxide and carbon dioxide contents of furnace flue gases are related to excess or deficiency of the air necessary for complete combustion, and he lays stress on the necessity for automatic gas analysis apparatus in order to obtain the best results from the fuel used. He applies his remarks to the cases of blast-furnaces and producers also.

H. E. Newall and F. S. Sinnatt, *The Combustion of Particles of Coal in Air; The Study of Cenospheres* (Fuel, 1926, vol. 5, Aug., pp. 335–339). A study of the behaviour of particles of caking coal under various conditions of heating. With coal from certain seams, cenospheres are formed when particles of all sizes between 60 and 90 mesh enter an inert atmosphere at a temperature of 550° to 575° C. It is found that cenospheres may be obtained from the vitrain and clarain components of coking seams, whilst particles of durain do not yield them. The object of the investigation was chiefly to determine whether cenospheres burn more readily than coal-dust particles. The results indicate that they are more readily inflammable than the original coal particles.

F. Dransfield, *Coal Testing and Combustion Calculations* (Electrical Review, Sept. 10, 1926, vol. 98, pp. 413–415). In making combustion calculations it is apparently usual to base all figures on pure carbon, and to calculate the approximate figures for the coal as being in direct proportion to the carbon content of the particular coal. The carbon content of the coal is, however, not usually known with certainty, and the author correlates a number of coal tests with a view to either obtaining the flue gas loss directly from the proximate analysis, or determining the carbon content more exactly from the proximate analysis, so that losses may be calculated by existing methods. He suggests that the calorific value based on the ultimate analysis should be used either directly, or as a check, in all important boiler tests.

M. de Coninck, *The Utilisation of Solid Fuels in Small Automatic Furnaces with Fusion of the Ashes* (Chaleur et Industrie, Aug. 1926, vol. 7, pp. 443–446). The author discusses the advantages of small installations over large ones, and advocates the use of "plastic coals" consisting of a mixture of coal and another material, such as tar or pitch, or even water. He suggests the use of a furnace into which the plastic fuel is fed slowly upwards through an orifice at the bottom, combustion taking place in a current of air passing downwards. This should give a high temperature, and the ashes would fuse and trickle down the outside of the fuel-feeding orifice. He describes further the uses to which such plants might be economically put.

R. Caillot, *The Control of Heating by the Analysis of the Gaseous Waste Products of Combustion* (Technique Moderne, Jan. 1, 1925, vol. 18, pp. 13–19). The author shows that for a given carbon dioxide content in the waste gases there may be two figures, differing widely, for the amount of heat lost. If, however, the combustible matter remaining

in the gas is known, these two figures may be discriminated. The author describes the Mono-Duplex, and Moerch and Roumet gas analysis apparatus for determining the amounts of CO_2 and incompletely burnt gases in waste gases, and indicates their method of operation and the types of diagram obtained. The heat losses are: (i) the sensible heat carried off by the gas, and (ii) the latent heat of the unburnt gases. In new installations fitted with every modern means of control the sum of these two losses should not exceed 17 per cent., but with very old plants it is sometimes difficult to keep under 30 per cent. The use and interpretation of the diagrams are explained.

E. G. Bailey, *Limiting Factors in Reducing Excess Air in Boiler Furnaces* (Paper presented to the American Society of Mechanical Engineers, Apr. 8, 1926: Mechanical Engineering, July 1926, vol. 48, pp. 703–709). A study of the inter-relationship and relative importance of the three factors most closely related to excess air—namely, furnace temperature, unburnt fuel, and heat loss in the chimney gases.

C. F. Wade, *CO_2 Records and their Interpretation* (Electrical Review, June 11, 1926, vol. 98, pp. 863–865). The author describes the effects on the carbon dioxide content and the temperature of the waste gases from a boiler furnace, caused by alterations to the many factors which enter into the control and manipulation of the fire, and shows how to set about getting maximum efficiency from the fuel burnt.

A. Grebel, *Optimum Carbon Dioxide Content of Flue Gases* (Chaleur et Industrie, 1926, vol. 7; June, pp. 307–315; July, pp. 389–394). The author discusses the conditions existing in a boiler furnace, and the relationship between the CO_2 content of the flue gases and maximum thermal efficiency of the boiler firebox. He points out how the attainment of economies in one direction may sometimes lead to excessive waste in other ways; the optimum CO_2 content is dependent on many factors.

P. Nettmann, *Determination of Unburnt Gases in Waste Gases* (Wärme and Kälte Techn., 1925, vol. 27, pp. 119–120). The author's apparatus consists of a filter and a small electrically-heated furnace containing CuO installed between the combustion chamber and a gas analysis apparatus. A five-way cock allows the burnt gases to pass either direct from the furnace to the gas analysis apparatus, or through the heater containing the CuO. A current of air may also be passed over the reduced copper to regenerate the CuO. The author claims for his apparatus convenience, simplicity, and automatic action.

Examination of Products of Combustion from Typical Gas Appliances.—Part I. (Gas Journal, Sept. 29, 1926, vol. 175, pp. 787–801). The Fifteenth Report of the Research Sub-Committee of the Gas Investigation Committee of the Institution of Gas Engineers. The investigation of the iodine pentoxide method of estimating carbon monoxide, the improvements that were introduced, and tests to determine the errors brought about by the presence of gases other than carbon monoxide, are dealt with very fully.

J. N. Waite, *The Combustion of Low-Grade Coal* (Electrical Review, Oct. 15, 1926, vol. 98, pp. 618, 619). The article deals with the utilisation of low-grade coal.

P. Solovioff, *Bituminous Schists as Industrial Fuel* (Chaleur et Industrie, Sept. 1926, vol. 7, pp. 501–508). The author describes experiments, and their results, made on bituminous schists from the middle basin of the Volga. He has designed a furnace, in which the volatile matter is expelled from the schist in a kind of retort and the fixed carbon is consumed in a sort of producer, the mixed gaseous products being burnt under the boiler. He considers that the rough tests made indicate that the method is feasible.

P. Solovioff, *Oil Shales as Industrial Fuel* (Engineer, Oct. 8, 1926, vol. 142, pp. 394–396). An English version of the above article.

O. C. Elvins and A. W. Nash, *Synthetic Fuel from Carbon Monoxide and Hydrogen* (Fuel, June, 1926, vol. 5, pp. 263–265). Investigations are being carried out in the Department of Oil Engineering and Refining at the Birmingham University on the synthesis of fuel from carbon monoxide and hydrogen, and a brief account is given of the preliminary work.

D. Aufhauser, *The Combustion and Chemical Utilisation of Coal* (Fuels and Furnaces, May 1926, vol. 4, pp. 563–565).

Pulverised Fuel.—*The Early History of Pulverised Fuel Firing* (Fuel Economist, Aug. 1926, vol. 1, pp. 521–524). The earliest recorded effort to burn coal in pulverised form was made by Niepoe in 1818, and it was not until nearly twenty years later that Henschel made the next attempt in 1831. About the same time Putsch, in England, attempted to apply this method to the manufacture of glass. J. S. Dawes used it in England in 1831 in blast-furnaces, injecting it with the air, through the tuyeres, and it was also proposed and tried in ironworks by Desboissierres in 1846, by Mouchel in 1854, and by Mushet in 1856. Crampton also used coal-dust in metallurgical furnaces (*see* Journal of the Iron and Steel Institute, 1873, p. 91). Powdered coal is stated to have been used in 1873 at Woolwich Arsenal for firing rotary puddling furnaces. Early American and German developments are also noted.

The Progress of Pulverised Fuel Firing (Fuel Economist, Jan. 1926, vol. 1, pp. 175–181). A summary of a report recently issued by the National Electric Light Association of New York on the developments and working of pulverised fuel plants in America. The report embodies a mass of data relative not only to actual working, but to the descriptions of fuels used and the difficulties encountered and overcome in practice. Boiler installations in the United States using pulverised fuel are now in operation in sizes varying from one unit of a few hundred boiler horse-power to eight units of 3000 boiler horse-power. A great variety of fuels is burned successfully in pulverised form. The fuels include lignites, anthracite culm, and low-grade bituminous coal from the Central Illinois district. In addition, the better grades of bitu-

minous coal and anthracite are represented. Petroleum coke was also tried in one instance, and while the difficulty of handling in pulverised form, due to its oily nature, might not have been serious, yet the small quantities available and the cost per ton would probably exclude it from consideration.

L. C. Harvey, *Some Suggestions on the Extended Use of Pulverised Coal for General Industrial Purposes* (Fuel Economist, July 1926, vol. 1, pp. 471–474). The author gives an outline of the economic side of pulverised coal applications, and some suggestions to eliminate certain difficulties.

W. Lulofs, *On Pulverised Fuels* (Chaleur et Industrie, Apr. 1926, vol. 7, pp. 177–182). The introduction of pulverised fuel for furnace heating resulted in such high temperatures that the refractory linings suffered unduly from the effects of the heat and of the fused ashes. The Lopulco system of cooling tubes in the firebox aimed at cooling the gases and ashes to an extent sufficient to reduce their injurious action on the refractories. The author has a system in hand in which the refractories are cooled by water-tubes, the latter (as in the Lopulco system) forming part of the boiler, and he sets out in the article the calculations necessary to determine the effect of the cooling in any given case.

G. B. Wharen, *The Economic Use of North Dakota Lignite for Steam Generation* (Mechanical Engineering, June 1926, vol. 48, pp. 583–585). The principal deposits and characteristics of North Dakota lignite are described. Firing methods, and the possibility of using the lignite in the pulverised form, and the cost of steam production, are discussed.

H. Nielsen, *Low-Temperature Solid Residuals as Powdered Fuel* (Iron and Coal Trades Review, Sept. 10, 1926, vol. 113, pp. 384–386). The author presents the result of tests on the use of low-temperature coke as a fuel in pulverised form. A powdered distilled residue, provided that it is the result of a low-temperature distillation, where the so-called primary oil products have been subjected to slight, if any, cracking, burns as freely as powdered raw coal.

Semi-Coke as Pulverised Fuel for Boiler Firing (Iron and Coal Trades Review, June 18, 1926, vol. 112, p. 975). Particulars are given of the plant and the results of tests carried out at the works of Messrs. Clarke and Chapman, Newcastle-on-Tyne, on the firing of boilers with pulverised semi-coke.

J. Wolff, *Tests of Pulverised Fuel-Fired Boilers at the Lake Shore Station, Cleveland* (Transactions of the American Society of Mechanical Engineers, 1925, vol. 47, pp. 1255–1266). An account of tests run to compare the results obtained with the guarantees, and to determine the general economy and detailed characteristics of the installation.

H. Kreisinger, *A Review of Recent Applications of Powdered Coal to Steam Boilers* (Transactions of the American Society of Mechanical Engineers, 1924, vol. 46, pp. 595–617). Gives a brief account of the modern trend of the development of powdered coal as a steam-raising

fuel. The furnaces, driers, and mills are discussed, and an account of certain tests is given.

Recent Progress in the Heating of Boilers by Pulverised Coal (Revue Universelle des Mines, 1926; vol. 11, Sept. 1, pp. 214–229; Sept. 15, pp. 274–286; vol. 12, Oct. 1, pp. 12–23; Nov. 1, pp. 97–102). The difficulties that have arisen, or are being still encountered, in the development and improvement of this system of boiler firing are discussed, and the various methods that have been, and are being, adopted to overcome them are described. Reference is made to the latest examples of the best practice in America, England, France, &c., and a review is given of the advantages of the system under the five headings: Economy of fuel, of material, of labour, high thermal efficiency, and flexibility of working. A bibliography of sixty references, besides footnotes, is appended.

G. W. Keen, *The Selection of Fuel-Burning Equipment for Generating Stations* (Mechanical Engineering, Sept. 1926, vol. 48, pp. 947–948). The author discusses the relative advantages and disadvantages of stokers and pulverised-fuel burning equipments.

H. W. Brooks, *Evolution of Combustion Volumes in Design of Boiler Furnaces for Pulverised Fuel* (Proceedings of the Engineers' Society of Western Pennsylvania, Feb. 1926, vol. 42, pp. 18–45).

Pulverised Fuel Plant and Boilers for Messrs. Synthetic Ammonia and Nitrates, Limited (Engineering, Sept. 24, 1926, vol. 122, pp. 381–383, 388, and Supplement).

Pulverised Fuel and the Efficient Generation of Power at the Collieries and in Industry (Fuel Economist, Mar. 1926, vol. 1, pp. 279–282).

E. G. Ritchie, *Pulverised Fuel in Relation to the Efficient Generation of Power at the Collieries* (Fuel Economist, May 1926, vol. 1, pp. 371–390). With the pulverised coal system of firing a higher operating efficiency can be maintained than with any other system of firing, while low-grade fuels, and fuels which are at present impracticable of use, may be successfully consumed. The Lopulco system is described in its several modifications, and the economic possibilities of this system are discussed, comparison being made between the total cost of steam production with pulverised fuel firing and with stoker firing. The effect of the extended application of pulverised fuel firing in industry is discussed in relation to colliery output and economy.

H. G. Barnhurst, *Pulverised Coal* (Paper read before the Engineering Institute of Canada, 1926: Iron and Steel of Canada, June 1926, vol. 9, pp. 159–161). A discussion of pulverised-coal-firing practice and its advantages.

K. C. Barrell, *Pulverised Coal* (Proceedings of the Institution of Mechanical Engineers, 1926, vol. 1, pp. 37–50). The preparation, burning, and applications of pulverised fuel are discussed.

F. M. Hartford, *A Successful Application of Powdered Coal as a Tunnel Kiln Fuel, Firing Hard-Fired Common Brick* (Journal of the American Ceramic Society, Oct. 1926, vol. 9, pp. 684–689). The

application of powdered coal to the firing of bricks in a continuous car tunnel kiln is described.

Burning Gasified Coal (Engineer, Sept. 3, 1926, vol. 142, pp. 256–257). The coal is pulverised and is then gasified by partial combustion in a cylindrical firebrick-lined chamber, which is fitted to the fire-door of the boiler furnace. As the gasified coal enters the firebox it meets the secondary air necessary for its complete combustion. The temperature in the gasifying chamber keeps within reasonable limits, and the flame in the furnace proper is well distributed, so that excessive wear on the refractory linings does not occur. A description of the system applied to a Paxman boiler, and a heat balance and other results of trials, are given. The same system is described under the title "*The Gasified-Fuel System of Burning Pulverised Coal*," elsewhere (Engineering, Sept. 3, 1926, vol. 122, pp. 294–296).

P. Dwyer, *Utilise Powdered Coal in Malleable Foundry* (Foundry, Sept. 1, 1926, vol. 54, pp. 666–669, 673). An illustrated account of the application of powdered fuel firing to melting and annealing furnaces and core-ovens at the plant of the Albion Malleable Iron Co., Albion, Michigan.

Multi-Stage Unit Pulveriser (Fuels and Furnaces, Feb. 1926, vol. 4, p. 227). Brief particulars are given of a multi-stage unit pulveriser designed principally for pulverising coal for the direct-firing of boilers, melting furnaces, and annealing ovens.

Malleable Melting Furnaces Equipped with Individual Coal Pulveriser (Fuels and Furnaces, Sept. 1926, vol. 4, pp. 1089–1090). Particulars are given of a reverberatory melting furnace fired with pulverised coal direct from the pulveriser.

L. P. Sidney, *Pulverised Fuel in Metallurgical Furnace Practice* (Metal Industry, Sept. 3, 1926, vol. 29, pp. 215–220). A description of the Buell system of pulverised-fuel firing.

Heat Losses.—A. Grounds, *The Determination of Heat Losses due to Radiation* (Fuel Economist, Jan. 1926, vol. 1, pp. 169–173). The author describes instruments for measuring radiation losses in boilers and furnaces. Insulating materials are briefly dealt with, and the use of magnesia and blast-furnace slag for this purpose is noted.

Power Plant.—F. R. Low, *Power Resources, Present and Prospective* (Transactions of the American Society of Mechanical Engineers, 1924, vol. 46, pp. 535–546). The author discusses the power resources of the United States of America, and reviews the various processes, and their efficiencies, by which these resources are converted; he outlines possible improvements in their use, and speculates on other sources of power which may be revealed by research.

C. W. E. Clarke and D. L. Galusha, *Modern Steam Power Stations* (Paper read before the American Iron and Steel Institute, May 21, 1926). The authors trace the developments in modern large power

stations, and enumerate and discuss the principal points of similarity in central station and steel mill power station requirements, when mill electrification is used. It is pointed out that high load factor and controllable power factor are two characteristics of the steel mill electrical load, which are superior to the typical central station load.

J. Breslove, *Whether to Buy Power or Make it* (Iron Age, May 6, 1926, vol. 117, pp. 1259–1263). An illustrated description of the newly erected power plant of the Pittsburgh Spring and Steel Co., Pittsburgh.

H. H. Dow, *Diphenyl Oxide Bi-Fluid Power Plants* (Paper read before the Association of Chemical Equipment Manufacturers, Cleveland, Ohio, May 14, 1926: Mechanical Engineering, Aug. 1926, vol. 48, pp. 815–818; Chemical and Metallurgical Engineering, Aug. 1926, vol. 33, pp. 475–476). The author first discusses the limits beyond which it is theoretically impossible to improve the efficiency of power plants using water and steam. The efficiency of the plant as a source of power may be increased, however, by the use of a liquid whose boiling point is higher than that of water. Emmett, who developed the "bi-fluid" system, proposed the use of mercury. The present author suggests the use of diphenyl oxide, and discusses its application, and the advantages which it possesses as compared to mercury.

J. G. Rollow, *Combined Oil- and Gas-Burning Furnaces for Power Plant Use* (Paper presented to American Society of Mechanical Engineers, June 28 to July 1, 1926: Mechanical Engineering, June 1926, vol. 48, pp. 683–685). The storage of gas on a scale large enough for dependable power-plant operation is not economical; it is therefore necessary to provide equipment which will utilise another fuel which can be stored. Such a fuel is oil. The paper describes apparatus with which both fuels may be used.

M. Roy, *On the Improvement of Thermal Plants and, in Particular, of Furnaces and Boilers of Steam-Engines* (Revue de l'Industrie Minérale, 1926; Oct. 1, pp. 429–446; Oct. 15, pp. 455–468). The author makes a systematic study of the more important improvements which have been introduced lately for the economisation of fuel by increasing the efficiency of steam-engine installations. They are considered first from the point of view of theory in order to demonstrate the mechanism of their action, and to evaluate the advantages that might be expected from their use in plant having a certain conventional degree of perfection. Then, by very simple and reasonably probable hypotheses, the probable benefit to be gained by their application to actual plant is calculated.

Waste Fuel Recovery.—H. S. Hatfield, *A New Magnetic Separator for Feebly Magnetic Minerals* (Bulletin of the Institution of Mining and Metallurgy, May 1926, No. 260). The author describes a magnetic separator in which the mineral powder to be separated is passed through a magnetic sieve consisting of several layers of iron wire placed in a

magnetic field, the direction of which is at right angles to the layers of the sieve. The magnetic material adheres to the wires of the sieve, while the non-magnetic material passes through. The separator can be used for wet or dry separation. An interesting application of the separator is to the purification of coke.

The Recovery of Unburned Fuel (Fuel Economist, Mar. 1926, vol. 1, pp. 251–253). The magnetic separation of fuel from ash and clinker is described, together with particulars of operating results.

Industrial Heating.—R. C. Gosreau, *Comparison of Gas and Electricity for Industrial Heating* (Chemical and Metallurgical Engineering, June 1926, vol. 33, pp. 337–339). When comparing gas and electricity count must be taken not only of the prime cost of each, but of the extent to which each permits of the utilisation of the available heat in the process under consideration, and the choice of heating agent must in every case be decided by the conditions which will hold good during its use.

H. H. Clark, *Industrial Fuels* (Proceedings of the Engineers' Society of Western Pennsylvania, Mar. 1926, vol. 42, pp. 100–108). A review of the modern fuels available, with special reference to coal-gas.

J. G. A. Rhodin, *Can the Heat of Combustion of Coal be turned directly into Electric Energy?* (Engineer, July 23, 1926, vol. 142, pp. 80–81). A review of some of the experiments and suggestions that have been made with the intention of obtaining the electrical equivalent of the heat of combustion from coal, and a survey of the directions in which modern research might turn in an attempt to achieve that result.

II.—*COAL.*

Africa.—*Coal in the Klip River Valley* (South African Mining and Engineering Journal, Mar. 20, 1926, vol. 37, pp. 55–56). The coal deposits in the Klip River Valley in the Transvaal are described. The field extends from the boundary of the farm Zuurbekom, which is between Potchefstroom and Johannesburg, a considerable distance west down the Wonderfontein Valley and south to the foot of the Gats Rand. The coal is of good quality, low in sulphur and ash. The area of marketable coal is estimated at 1000 acres.

F. Dixey, *The Sumbu Coal Area, Nyasaland* (Mining Magazine, 1926, vol. 34, p. 148). The Sumbu district, which is in the extreme south of Nyasaland, is covered by rocks of Karroo age, which extend west to the Zambesi River, and are known to contain coal seams. A seam of coal 7 feet in thickness has been found 4 miles west of Chundisa. The area was surveyed by the author in 1923–24 and thirteen outcrops were sampled, all close to the Nkombedzi River and its tributaries. The seams, from 3 to 12 feet thick, were much weathered. The coals improved greatly in depth; the best quality yielded on analysis: fixed

carbon 51·44, volatile matter 24·86, ash 18·97, moisture 4·79, and sulphur 0·59 per cent. The calorific value was 10,214 B.Th.U.

Australia.—E. J. Kenny, *The Coal Resources of New South Wales* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1304–1308). The coal-bearing rocks of New South Wales are classified geologically, and brief descriptions are given of the coal measures.

W. Baragwanath, *Coal Resources of Victoria* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1309–1313). A brief description is given of the black and brown coal deposits of Victoria.

Canada.—W. S. Wilson and M. W. Booth, *The Characteristics and Utilisation of Nova Scotia Coals* (Paper read before the Engineering Institute of Canada: Canadian Mining Journal, Sept. 3, 1926, vol. 47, pp. 861–863). The coals of Nova Scotia with few exceptions are of the first-rank bituminous, highly volatile, with high calorific values and low moisture and ash content. They possess good coking properties, and are suitable for all general and metallurgical purposes. A table is given showing analyses of typical mine samples.

France.—M. Stouvenot, *The Results and Innovations of the Exploitation of Coal in Le Nord in* 1925 (Revue de l'Industrie Minérale, June 15, 1926, pp. 279–282). The author reviews the production of coal in the department of Le Nord, France, for the years 1919 to 1925, and shows that the production for 1913 was already exceeded in 1923, although reconstruction was still incomplete. The production of coke also shows a marked increase. This greater production is attributed to the employment of more workpeople, and to the fact that the opportunity has been taken in repairing the ravages of the war to put in plant of the most up-to-date pattern.

Great Britain.—*Physical and Chemical Survey of the National Coal Resources: No.* 6, *The King Seam* (Department of Scientific and Industrial Research, Fuel Research Board, 1926). The report describes laboratory experiments carried out by the Lancashire and Cheshire Coal Research Association. The King seam is recognised over a considerable area of the Lancashire coalfield, and has been extensively worked in some areas. It is a bituminous, moderately caking coal, and is mainly used for manufacturing purposes. The content of volatile matter is high, ranging from 36 to 43 per cent. The ash content of the seam varies considerably in different districts, and also frequently in different horizons in the same section. The behaviour of the coal during carbonisation in the laboratory assay apparatus at a temperature of 600° C. has been studied.

C. T. Clough, L. W. Hinxman, W. B. Wright, E. M. Anderson, and R. G. Carruthers, *The Economic Geology of the Central Coalfields of Scotland, Area V.* (Memoirs of the Geological Survey, Scotland, 1926). This is the second edition of a memoir first published in 1916 describing the economic geology of an area of about 100 square miles, extending from Glasgow westwards to beyond Longriggend in the central coal-field of Scotland.

F. N. Trotter, *Geology of the Carlisle, Longtown, and Silloth District* (Great Britain: Geological Survey, London, 1926). An account is included of the coal measures of the Solway Basin.

Summary of Progress of the Geological Survey of Great Britain for the Year 1925 (H.M. Stationery Office, London, 1926). The report contains a brief account of the results of the Survey's work in the United Kingdom. In nearly all the important coalfields surveyors are at work revising the old geological maps, and the present report contains much new information regarding the general geology and the special details of the worked seams in these fields.

The Kent Coalfield (Colliery Engineering, May 1926, vol. 3, pp. 198–202). A note of the discovery of this field, the character of the coal, and the present position of mining activity in the county.

Report of the Royal Commission on the Coal Industry (1925) (Revue Universelle des Mines, July 15, 1926, vol. 11, pp. 73–79). Translated into French and abstracted by R. Touwaide.

Russia.—L. Ramzine, *Division of the Donetz Basin into Districts Corresponding to the Different Classes of Coal* (Chaleur et Industrie, Aug. 1926, vol. 7, pp. 434–436).

United States.—J. A. Bownocker, *The Pittsburgh Coal-Bed of Ohio* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The Pittsburgh coal-bed is one of the most important in Ohio, and extends from Jefferson County south-west to Lawrence County, at least 150 miles. Large deposits are found in three fields, Belmont, Federal Creek, and Gallia, which are described, with the composition of the coal and structure of the bed in each.

G. H. Ashley, *The Pittsburgh Coal-Bed of Pennsylvania* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The extent and value of the Pittsburgh coal-bed is shown, with a map of the area. The use and importance of the coal mined, its variable character, thickness and structure, and quality, are discussed. A typical section of the coal is illustrated, and a table gives analyses of the coal from the several basins in the State. The coal reserves of the bed by counties are also tabulated.

Analyses of Missouri Coals (United States Bureau of Mines, 1926, Technical Paper 366). Numerous analyses are given of coal samples from Missouri, together with a brief account of the topography and geology of the coal areas, and mining methods.

Constitution and Chemistry of Coal.—S. W. Parr, *Constitution of Coal* (Industrial and Engineering Chemistry, June 1926, vol. 18, pp. 640–648). Ordinary coal subjected for forty-five days to a current of oxygen at 100° C. increased in weight by 7 per cent. In the same period 8·5 per cent. of moisture and 6 per cent. of carbon dioxide were formed. With the oxygen at normal temperature an increase of weight of 2 per cent. took place in forty-six days. The melting or softening point of coal was found to be dependent on the bituminous substances.

R. V. Wheeler, *The Constitution of Coal* (Journal of the Society of Chemical Industry, Sept. 10, 1926, vol. 45, pp. 307–310). A general review of the recent progress in the study of the constitution of coal. Ordinary bituminous coal consists mainly of a matrix of insoluble ulmin compounds, the degradation products of the less resistant plant tissues in which varying proportions of morphological organised plant tissues and plant substances devoid of morphological organisation that have escaped ulmification are dispersed. It remains to examine the chemical character of the plant entities which may give characteristic properties to the coals containing them and of the matrix.

W. Francis and R. V. Wheeler, *Resins in Coal. Studies in the Composition of Coal* (Journal of the Chemical Society, June 1926, pp. 1410–1412). An account of experiments by which the presence of resins in a bituminous coal was revealed. Their occurrence was best demonstrated in the vitrain portion of a banded bituminous coal, and the authors are now of opinion that a completely structureless vitrain is a rarity.

E. Audibert, *On the Mechanism of the Fusion of Coal* (Comptes Rendus, Feb. 1926, vol. 182, pp. 316–318). All coals containing more than 14 or 15 per cent. volatiles undergo softening when heated at a sufficiently rapid rate, so agglomerating into a compact mass. The limiting rate of heating for coals used industrially in the manufacture of metallurgical coke is 1° C. per minute. But other coals also, if heated at a suitable rate, will give a compact coke having a resistance to crushing of more than 1 kilogramme per square millimetre. This is due to the fact that the temperature of gasification of the coals is slightly below the fusion temperature (325° to 450° C.); when the rate of heating is slow the fusible constituents have the opportunity to decompose, at least partially, before the softening takes place.

E. Audibert, *The Transient Fusion of Coal* (Fuel, June 1926, vol. 5, pp. 229–244). The article is an English translation in full of the author's work on the factors controlling the quality of blast-furnace coke (Revue de l'Industrie Minérale, Mar. 15, 1926, pp. 115–136; *see* Journal of the Iron and Steel Institute, 1926, No. I. p. 519).

N. Simpkin, *Composition of Durain* (Transactions of Society of Chemical Industry, 1926, vol. 45, pp. 76–78). Analyses of durain from a number of Lancashire seams show that it contains 1·16 to 28 per cent. of ash, which is generally white or very pale brown, and melts

above 1400° C. The content of volatile matter varies very considerably, and the coking value is less than that of the remainder of the coal.

L. Crussard, *Vegetable Substances and Coals and their Relations to Chemistry* (Revue de l'Industrie Minérale, 1926; May 15, pp. 219–234; July 1, pp. 283–295; July 15, pp. 303–316). The study of vegetable substances and coals is of course a matter of organic chemistry, but the chemical reactions that occur in nature are widely different from those that can be made to take place in the laboratory. Whereas man has succeeded in producing a vast array of chemical combinations, nature restricts herself to a surprisingly small range. Again, those reactions which the laboratory chemist considers of prime importance are by no means the most important ones in natural chemistry, and, while the chemist makes use of energetic reagents like the alkalis, the peroxides, magnesium organic compounds, &c., nature ignores them. Though complicated in their mechanism, the natural reactions are generally very simple; molecular rupture (cracking), polymerisation, combination with the elimination of water, hydrolysis, oxidation and reduction, these appear to complete the list. This then points to a highly specialised organic chemistry, and it is this special chemistry which the author has attempted to review and summarise in the first part of the paper. The second part deals with the application of this specialised chemistry to vegetable tissues, and the remainder treats of the combustibles produced from the latter after their death.

Oxidation, Storage, and Spontaneous Combustion of Coal.—J. D. Davis and D. A. Reynolds, *The Oxidation of the Constituents of a Resinous Utah Coal* (Fuel, Sept. 1926, vol. 5, pp. 405–411). The report describes experiments carried out by the United States Bureau of Mines.

B. Moore and F. S. Sinnatt, *An Investigation of the Behaviour of Solid Fuels during Oxidation* (Fuel, Sept. 1926, vol. 5, pp. 377–380). The experiments show that the ignition properties of coal undergo a marked alteration during prolonged storage, the result being a diminution of the tendency of the coal to ignite.

E. Sinkinson and H. G. Turner, *Adsorption of Carbon Dioxide by Coal* (Industrial and Engineering Chemistry, June 1926, vol. 18, pp. 602–605). Coals of all grades adsorb carbon dioxide, with an attendant rise in temperature, and the gas is very tenaciously held. The phenomenon is more marked with high- than with low-grade coals. The natural charcoal content of high-grade coals has a greater adsorptive power than the charcoal of bituminous coals. Although the charcoals from different grades of coal are similar in appearance their behaviour towards carbon dioxide is not. The charcoals from the coals are relatively less active towards the gas than are artificially prepared charcoals, the charcoals behaving very much like the coals from which they are taken. Water-saturated carbon dioxide is adsorbed to a greater extent than the dry gas, and in the case of a mixture of carbon

dioxide and oxygen the degree of adsorption is directly proportional to the partial pressures of the gases in the mixture.

S. W. Parr and R. T. Milner, *Oxidation of Coal at Storage Temperatures* (Fuel, July 1926, vol. 5, pp. 298–301). S. W. Parr, *Deterioration and Spontaneous Combustion of Coal in Storage* (Fuel, July 1926, vol. 5, pp. 301–305). S. W. Parr and C. C. Coons, *Carbon Dioxide as an Index of the Critical Oxidation Temperature for Coal in Storage* (Fuel, July 1926, vol. 5, pp. 306–308). The foregoing three papers contain the results of investigations, carried out at the University of Illinois Fuel Station, of the temperature conditions under which oxidation of coal occurs in storage.

D. J. W. Kreulen, *The Change in Weight of Coal during Prolonged Oxidation at Low Temperatures* (Fuel, Aug. 1926, vol. 5, pp. 345–346). The author describes experiments of a kind similar to those of Parr and Milner, referred to above, and compares his results with theirs. The author's tests were made with Scottish coal.

H. Macpherson, N. Simpkin, and S. V. Wild, *Pyritic Oxidation in Relation to the Spontaneous Combustion of Coal* (Mines Department: Safety in Mines Research Board, 1926, Paper No. 26). The principal object of the research described was an examination of the various types of pyrites occurring in coal, with a view to determining their composition, and to distinguishing between those types which oxidise rapidly, and those which do not. A laboratory study has been made of the rates at which varieties of pyritic material oxidise, and of the character of the products formed; and the results have been correlated with observations on the behaviour of the material *in situ* in the mine. The results emphasise the importance that must be attached to the mode of existence of pyrites when considering its probable influence on the spontaneous combustion of coal.

W. Francis and R. V. Wheeler, *The Spontaneous Combustion of Coal* (Mines Department: Safety in Mines Research Board, 1926, Paper No. 28). An account is given of recent work designed to determine which constituents of the coal conglomerate are most readily attacked by oxygen. Whilst the presence of pyrites may be a contributing or even a determining factor, the main cause of the spontaneous combustion of coals is the direct action of the oxygen of the air on the coal substance. The results show that the portion of the coal conglomerate that must be held responsible for its spontaneous combustion is the ulmin portion, the characteristics of which have been examined in some detail. The relative degree of liability of a particular coal, chemically, to spontaneous combustion can be remedied by determining the proportion and character of the ulmin compounds that it contains.

J. H. H. Nicolls, *The Effects of Exposing Canadian Lignite to Atmospheres of Different Humidities* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1924, pp. 36–44). Typical Alberta coals, both crushed and finely ground, were exposed to the indoor atmosphere under conditions of low and high humidity.

The coals were exposed either raw or almost dry, and curves are given showing the variations in moisture content under the changing conditions. Consideration of the various schemes of classification has led to the conclusion that the percentage of moisture in air-dried coal is a valuable basis for classification.

J. H. H. Nicolls, *Friability Tests on Various Fuels Sold in Canada* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1924, pp. 20–35). A standard form of tumbling test was devised, by means of which the relative friabilities of a number of representative fuels were determined. The tests were carried out on weathered and unweathered fuels.

Coking Properties of Coal.—W. A. Bone, *The Coking Propensities of Coal* (Chemistry and Industry, Sept. 3, 1926, vol. 45, pp. 646–647). In conjunction with others the author published in 1924 (Proceedings of the Royal Society, (A), vol. 105, p. 608) the results of a systematic investigation of the nature of the benzene extracts from coal, and by a new solvent treatment they divided crude benzene extract into four fractions of which Nos. I. and IV. were the most important in their relation to the constitution of coal. Fraction I. was a thick reddish-brown non-nitrogenous oil, while fraction IV. always consisted of amorphous cinnamon-brown powders containing small amounts of both nitrogen and sulphur, with softening points between 185° and 230° C. and the ultimate compositions varying between: carbon 88·5 to 88·7, hydrogen 5·4 to 5·9, nitrogen 1·1 to 1·5, sulphur 0·4 to 0·9, and oxygen 3·1 to 4·9 per cent. It exhibited considerable binding properties when carbonised at 900° C. in admixture with 9 times its weight of dry coke dust, and the coking propensities of bituminous coals were proportional to their yield of this fraction. This view has been challenged by Fischer (Brennstoff-Chemie, 1925, pp. 33, 349), who seems to conclude that fraction I. is chiefly responsible for the coking propensities. Further experiments now made by Bone confirm his previous conclusion. Briefly, Durham coals with less than 2 per cent. of fraction IV. does not coke at all, and the best Durham coking coal is found to contain 7 per cent. of the fraction. This fraction IV. is, however, not the sole cause of coking; fraction III., a non-nitrogenous substance, less than 1 per cent. of which is usually present in bituminous coal, is also a contributory factor.

H. J. Rose, *Selection of Coals for the Manufacture of Coke* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926: Colliery Guardian, 1926, vol. 132; Aug. 20, pp. 401–403; Aug. 27, p. 462). The paper deals with the selection of coals for the manufacture of blast-furnace, foundry, domestic, and water-gas coke in by-product coke ovens. The physical and chemical characteristics of the different types are discussed. Methods are described for determining the quality of coke that can be produced from a given coal, and the relations between the chemical composition and coking properties of

coal are indicated. With blast-furnace coke it is pointed out that permissible ash content will range from 8 to 16 per cent.; sulphur content should not exceed 1·3 per cent., and phosphorus should be less than 0·01 per cent.

F. Fischer, H. Broche, and J. Strauch, *The Coking Properties of Coal* (Fuel, Oct. 1926, vol. 5, pp. 466–475). The article is an abridged translation of the authors' paper on the components of the coal bitumens and the part played by the individual components in the swelling and caking of the coal (Brennstoff-Chemie, 1926, vol. 6). The coals selected for the experiments included non-caking coal of recent geological age, gas-coal, coking and anthracitic coal, and were typical products of the Ruhr, Saar, and the Upper Silesian coalfields. The experiments showed that coal can be deprived of the constituents which determine caking and swelling. The extracted composite bitumen consisted of two portions of oil or liquid bitumen and solid bitumen. The oily bitumen imparts the power of caking to coals, and if present in sufficient quantity causes the coals to soften during carbonisation and thus yield a good coherent coke. The solid bitumen is responsible for the swelling of coal, if its temperature of decomposition coincides with the temperature at which the coal softens. By determining the absolute quantity of total bitumens in a coal, the relative proportions of oily and solid bitumens in the extract and the decomposition temperature of the solid bitumen, good indications of the coking characteristics of a coal can be obtained.

R. Kattwinkel, *Examination and Evaluation of Coking Coal* (Gas und Wasserfach, Feb. 1926, vol. 69, pp. 145–148; Fuel, Aug. 1926, vol. 5, pp. 347–355). The author reviews the methods of examination of coals in the laboratory, and points out that the results of such tests are by no means conclusive, because the conditions do not reproduce those pertaining to large-scale work. This is particularly true of the rate of transmission of the heat. The production of a compact coke from lean coals is not possible, according to Fischer's theory, consequently its accomplishment must involve forces which are very difficult to determine experimentally. Probably the carbon molecules may undergo modification during the process, with a consequent powerful influence on the properties of the coke.

J. D. Davis and D. A. Reynolds, *The Coking Constituents of Mesa Verda and Pittsburgh Coals* (Industrial and Engineering Chemistry, Aug. 1926, vol. 18, pp. 838–841). Presented under the title "The Coking Constituents of Castlegate and Pittsburgh Coals" at a meeting of the American Chemical Society, Apr. 5–9, 1926. The coking constituents were investigated by Fischer's method; the coal bitumens were extracted by benzene under pressure, separated into solid and oily bitumens by petroleum ether, and tested separately by the volatile matter coking test. Contrary to Fischer's findings, the solid bitumen possessed stronger agglomerating power than the oily bitumen, and neither produced appreciable swelling of the coke. Pressure extraction

with benzene did not remove all the agglutinating constituents from the coal. The conclusiveness of the volatile matter test for estimating the coking power of coal constituents is doubted.

Strache and C. Mika, *Crucible Coking for Testing Coal* (Gas World, Coking Section, July 3, 1926, vol. 85, p. 86). A summary of an article in Gas und Wasserfach. The ordinary crucible coking test for fuels was investigated, and it was found that the influence of the amount of air mixed with the gas in the Bunsen burner was so profound that the internal temperature of the crucible could in no way be controlled by stating the height of the free flame and the position of the crucible only. The material of the crucible affected the rapidity of coking, but not the yield. The thickness and conductivity of the crucible was also without effect on the final temperature of the crucible interior, but the radiation properties of the crucible surface had a marked effect.

B. F. Haanel and R. E. Gilmore, *Coking Experiments on Coals from the Maritime Provinces* (Canada, Department of Mines, Mines Branch, Investigations of Fuels and Fuel Testing, 1924, pp. 1–19). The results are given of an investigation of the suitability of coals from the Maritime Provinces of Canada for the manufacture of coke. A laboratory examination of survey samples, coking tests, and burning tests, and small-scale coal washing tests, were carried out. Tables are included showing the chemical composition of coal samples from New Brunswick and Nova Scotia.

R. A. Strong, *Report of Carbonisation and Washing Experiments on Sub-Bituminous Coal from Coal Valley, Alberta* (Canada Department of Mines, Mines Branch : Investigations of Fuels and Fuel Testing, 1924, pp. 60–68). The results of chemical analyses showed that the coal from Coal Valley, Alberta, was typical of the sub-bituminous coals from the Coalspur area. The lump coal with 8·7 per cent. ash had a calorific value of 11,255 B.Th.U. per pound, whereas the slack coal with 21·2 per cent. ash had a calorific value of 9325 B.Th.U. The screen analysis of the slack coal and the determination of the ash content of various screened portions showed that the ash was fairly uniformly distributed throughout the various sizes, and that no appreciable reduction in ash would be effected by screening. Washing experiments conducted on the slack coal in three different types of laboratory machines showed that it is difficult to reduce the ash content below 15 per cent. by flotation or ordinary table methods. By means of sink and float experiments carried out with solutions of carbon tetrachloride and benzene of different densities, the ash content of the slack was readily reduced to below 10 per cent. Laboratory carbonisation tests conducted at 600° C. on both the lump and slack coal showed yields of residue and by-products equal to those from other Alberta sub-bituminous coals. The calorific value of the carbonised residue from the unwashed coal was, however, appreciably lower, due to the high ash content.

R. Quarendon, *The Cause of Coking in Coals* (Chemistry and Industry, 1926, vol. 45 ; July 9, pp. 468–470 ; July 16, pp. 483–487). A review

of the work and conclusions of various investigators on the coking properties of coal.

Formation of Coal. E. McK. Taylor, *Base Exchange and its Bearing on the Origin of Coal* (Fuel, May 1926, vol. 5, pp. 195–202). Numerous theories have been put forward to account for the formation of coal, but so far there is none which gives a satisfactory explanation of the formation of any other decomposition product of vegetable matter except peat. It is suggested that coal has resulted from two types of bacterial decomposition—the first resulted in the production of peat during the accumulation of the vegetable bed, the second type of action was carried on under alkaline, anærobic conditions under an alkaline layer of clay, produced as the result of base exchange between clay and solutions of sodium chloride. The product of the decomposition of peat would then be a reduction compound which, it is suggested, would be coal substance.

H. Stille, *The Formation of Mineral Coal Considered as a Technical Problem* (Braunkohle, Jan. 16, 1926, vol. 24, pp. 913–918). The author develops the study of the differences between the old and new coal formations. The older seams were formed in places where considerable movement has taken place; the result is a large number of seams of coal, each of only little importance. On the other hand, the more recent coals have been formed in places which have suffered very little movement; as a consequence the seams are but few, but are of great size.

R. Vigier, *The Practical Interest and Application of the Palæontological Study of a Coal-Bearing Terrain* (Revue de l'Industrie Minérale, Aug. 1, 1926, No. 135, pp. 345–354). The paper indicates what information may be extracted by a palæontological study of a coal-bearing terrain, particularly by the method described by Barrois. Examples are quoted to show the services already rendered by the method, and to demonstrate that it is easily applied without the necessity for a very wide experience in palæontology.

Peat.—B. F. Haanel, *Peat: its Manufacture and Uses* (Canada, Department of Mines, Mines Branch, Final Report of the Peat Committee, 1925). Part I. of the Report deals with the character and qualities of peat as a raw material for the production of fuel, the development of the peat industry in Europe, and the extent of the peat resources of Canada. The development of methods of peat fuel manufacture is traced, and the more recent machines employed in the manufacture of air-dried machine peat are described and illustrated. The section of the Report on the dehydration of peat is of special importance. Numerous failures have resulted from attempts to accomplish the dehydration of peat by what may be termed artificial methods, in contradistinction to the natural air-dried process. The field operations of the Committee at Alfred, Ontario, the machines developed, and its findings and conclu-

sions in relation to the several matters involved in the investigation, are comprised in Part II. of the Report; while Part III. is devoted to special applications and uses of peat fuel, including a description of the experiments conducted in the carbonisation of air-dried peat.

W. W. Odell and O. P. Hood, *Possibilities for the Commercial Utilisation of Peat* (United States Bureau of Mines, 1926, Bulletin 253). The report discusses the commercial and economic practicability of utilising peat as a fuel in the United States. The winning of peat fuel, drying and carbonisation of peat and recovery of by-products are discussed at considerable length.

III.—*COKE.*

Manufacture of Coke.—E. V. Evans, *Research on the Destructive Distillation of Coal* (Gas World, Mar. 1, 1924, vol. 80, pp. 170–176).

E. V. Evans, *A Study of the Destructive Distillation of Coal* (Gas World, Mar. 8, 1924, vol. 80, pp. 197–207).

S. Qvarfort, *Relation between Coal Analysis and Carbonisation Products* (Gas Journal, Oct. 6, 1926, vol. 176, pp. 33–36). The author puts forward graphical curves to show the relationship which exists between the products of carbonisation and constituents of the coal before carbonising. The curves are all obtained empirically, but a table is reproduced which shows very good agreement between the values shown by the graphs and actual yields.

H. M. Boylston, *Blast-Furnace Fuels* (Fuels and Furnaces, May 1926, vol. 4, pp. 529–536). The requirements of a blast-furnace fuel and the relative value of fuels are discussed. The manufacture of charcoal and coke and the value of fluxes are also dealt with.

Studies in Carbonisation. Part I.—Influence of Size of Coal (Gas Journal, Sept. 29, 1926, vol. 175, pp. 802–826; Gas World, Sept. 25, 1926, vol. 85, pp. 298–311). The Sixteenth Report of the Research Sub-Committee of the Gas Investigation Committee of the Institution of Gas Engineers. The experiments described in this report constitute the first stage of an investigation commenced with the object of studying the influence of various factors on the yields, and chemical and physical properties, of the products obtained when different types of coal are carbonised. The gas coal experimented upon was obtained from Nottinghamshire.

G. E. Foxwell, *Volatile Matter in Coke* (Gas World, Coking Section, Sept. 4, 1926, vol. 85, pp. 102–105). The author debates the advisability of completely expelling all volatile matter from coke. For coke ovens having no sale for gas the expulsion of the last traces is not worth while, but for gas works the matter becomes a question of whether the additional cost involved in the removal of the entire volatile matter is counterbalanced or not by the additional saleable "therms" obtained.

The composition of the volatile matter in coke is also discussed, as this is one of the factors on which the final decision must be based.

E. X. Schmidt, *Gas is Regulated Automatically* (Iron Trade Review, Aug. 19, 1926, vol. 79, pp. 441–444). The automatic recording instruments in use at an American by-product coking plant are described, and particulars are given of their manipulation.

F. Müller, *Comparative Investigations of Dry-Cooled and Water-Quenched Coke* (Glückauf, Aug. 28, 1926, vol. 62, pp. 1128–1132). It is generally admitted that dry-cooled coke ignites more readily than quenched, though the reason for this is not yet fully explained. In any case if the surface of the dry-cooled coke is slightly wetted its ability to ignite becomes about normal. In appearance dry- and wet-quenched coke are about the same. The capacity of dry coke to absorb moisture was tested, and it was found that when spread out and exposed to a very moist atmosphere for 4 weeks the moisture absorbed by the coke was only 0·08 per cent. The total sulphur content of dry coke is found to be about 0·055 per cent. more than in quenched coke, but practically the whole of the excess consists of sulphide sulphur. Otherwise the differences in chemical composition are negligible. The chief advantages of the dry-cooled coke are its dryness and its lumpiness; the proportion of smalls and breeze is considerably less. Moreover, in transporting it the consumer does not have to pay carriage for water.

Economic Coke Quenching (Colliery Engineering, Aug. 1926, vol. 3, pp. 360–361; Gas Journal, July 14, 1926, vol. 175, p. 86). Illustrated particulars are given of the Heller-Bamag coke-quenching plant. Coke is quenched inside a steam-tight chamber by a spray of highly superheated water. The steam and gases evolved during the quenching process are used for the production of high pressure live steam in a generator. As a result of the treatment of the coke the sulphur content is reduced. The entire plant is operated by one man, the duration of each quenching period is fifteen minutes, and the coke leaves the plant at a temperature of about 100° C. It is possible with this plant to adjust the percentage of moisture content in the quenched coke.

C. F. Ellwood, *Coke Quenching and Handling* (Paper read before the Coke Oven Managers' Association: Iron and Coal Trades Review, July 2, 1926, vol. 113, pp. 14–15). The various methods of coke quenching are enumerated, and brief particulars are given of the Greensmith and Goodall systems of quenching.

Goodall Coke-Quenching and Loading Machine (Iron and Coal Trades Review, July 16, 1926, vol. 113, pp. 83–84). Illustrated details are given of the construction and operation of this machine. The coke is pushed direct on to a revolving table, surrounded by a screen, where it is sprayed. The whole machine is mounted on rails, and is moved for discharging. The coke is discharged from the table on to a jigging screen, and direct into wagons. Only two men are required to quench, screen, and load the coke into trucks.

C. Berthelot, *Recent Progress in the Construction and Exploitation of*

Coke-Ovens (Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Mar. 1926, vol. 125, pp. 145–183). The author makes a detailed survey of the progress in plant and processes which has been made in recent years in the manufacture of coke. He classifies the improvements under three heads:—(A) Constructional: The use of silica bricks for the walls of the heating chambers; more suitable dimensions for the retorts (width decreased and length and height increased); better arrangement of the flues leading in the combustible gases, resulting in more even heating and less back-pressure; reduction of heat losses. (B) Plant: The use of large-capacity charging machines, perfected gear for removing the oven doors; powerful and rapid dischargers; simple and strong mechanical means of quenching and handling the coke, and more economical and robust gas-reversing gear. (C) Quality of the coke and gas: The production of a better coke for blast-furnace use, on account of its better combustibility, and gas with higher calorific power, because of the increased gas-tightness of the oven doors.

H. J. Rose, *Relation of By-Product Coke-Ovens to the Natural Gas Supply of the Pittsburgh District* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). Decrease in the production of natural gas and the increasing use of manufactured gas as fuel in the Pittsburgh district are discussed, and the methods of manufacture and the advantages of coal gas from by-product ovens are reviewed. Recent developments in coke ovens designed to burn either coal-gas or producer-gas are described, with special comment on the Becker oven.

H. Kuhn, *The "Still" Multi-Flame Coke-Oven* (Iron and Coal Trades Review, July 9, 1926, vol. 113, pp. 50–53). The constructional details of this oven are described, and the advantages of the multi-flame system of heating are discussed.

G. Chrisp, *Coke-Oven Plant Stoppages* (Paper read before the Coke-Oven Managers Association: Iron and Coal Trades Review, June 11, 1926, vol. 112, p. 921). The author discusses the procedure of closing down coke-ovens in the event of a stoppage, and their restarting.

D. M. Rugg, *Serving Two Plants with Coke* (Iron Age, July 15, 1926, vol. 118, pp. 145, 192–194). At the plant of the Donner Hanna Coke Corporation at Buffalo, consisting of three batteries of Koppers ovens, the bulk of the coke produced went to two groups of blast-furnaces. It was found that the coke used successfully by one group was far from satisfactory to the other. Experiments were conducted with coal mixtures, and two types of coke are now produced in the same plant, resulting in notable improvements in the performances of both groups of furnaces. Tables are included showing the operating results on the blast-furnaces for several months after the change, also the analysis of coal and coke and the coal mixture used.

G. Keppeler, *Peat Gas and Peat Coke* (Stahl und Eisen, 1926, vol. 46; May 13, pp. 631–635; June 3, pp. 742–750). Practice in the distillation

of peat, the production of peat gas and of peat coke is described, with illustrations of the producers and peat coke-ovens. Peat coke from the bogs of Oldenburg contains about 0·30 to 0·35 per cent. sulphur and 3 to 4·5 per cent. ash, with a heat value of about 7000 calories. The coke has a low ignition temperature and a high reactivity, and is very suitable for metallurgical purposes. The principal by-products recovered are acetic acid, methyl alcohol, and acetone.

Properties of Coke.—W. A. Haven, *Notes on Coke Testing* (Paper read before the American Iron and Steel Institute, May 21, 1926). The author describes in detail the procedure followed by the Republic Iron and Steel Company of Youngstown for the testing of blast-furnace coke. The importance of combustibility of coke and its effect on the driving rate of blast-furnace operation is commented on, and particulars are given of combustion, tumbling and sizing tests, and methods of chemical analysis.

T. T. Read, *What Combustibility Means* (Iron Age, July 8, 1926, vol. 118, pp. 76–77). The misuse of the term "combustibility" is pointed out, and the suggestion is put forward for the use of the word "flammability," which is defined as "susceptibility of taking fire readily."

P. Oberhoffer and E. Piwowarsky, *Influence of Moisture on the Combustion Process, in Particular on the Combustion of Coke* (Stahl und Eisen, Sept. 30, 1926, vol. 46, pp. 1311–1320). Combustion tests on coke were made in open shaft furnaces, using an air-blast carrying different proportions of moisture. In some tests water was injected into the blast, in others the blast contained the natural amount of moisture according to the season. In general, the results show that:

1. Air with a low proportion of moisture (3·5 to 4·5 grammes per cubic metre) raises the maximum temperature of combustion, lowers somewhat the position in the furnace of the temperature and carbon dioxide maxima, and increases the proportion of carbon monoxide in the waste gases.

2. A medium proportion of moisture in the air (8·5 to 10·7 grammes per cubic metre) causes an increase of carbon monoxide in the waste gases, but noticeably reduces the maximum furnace temperature and scarcely affects the position of the temperature and carbon dioxide maxima.

3. At higher proportions of moisture (11 to 12·5 grammes per cubic metre) the furnace temperatures fall considerably, the position of the temperature and carbon dioxide maxima is raised again, and the waste gases are richer in carbon dioxide.

4. At maximum proportions of moisture (15 to 26 grammes per cubic metre) the furnace temperatures are still further lowered, the proportion of carbon dioxide is greatly reduced, carbon monoxide is formed in large volumes before the oxygen of the air is fully consumed, and the waste gases are again richer in carbon monoxide.

5. In judging the influence of moisture the quantity of moisture entering the furnace per unit of time is a better criterion than the amount of moisture per cubic metre of the blast.

6. Moisture artificially introduced by the injection of water into the blast has a more favourable influence than the same amount of moisture naturally present in the air. The temperature of combustion is 50° to 65° higher, and the speed of carbon dissociation of the coke is increased by 1·5 to 14·5 per cent. An increase in the volume of the blast from 25 to 45 cubic metres per hour, also the preheating of the blast to 400° influences the combustion conditions in the same sense as a low proportion of moisture (as in (1) above), but more strongly. The authors are of opinion that the cause of the remarkable influence of small quantities of steam when blown into burning coke is to be found in the increased radiation capacity of the gas phase containing the vapour, which reacts on the speed of the heat transmission, without ignoring, however, the possibility of a chemical catalytic effect.

F. Häusser and R. Bestehorn, *Combustibility and Strength of Blast-Furnace Coke in Medium-Sized Lumps* (Berichte der Gesellschaft für Kohlentechnik, 1926, vol. 1, pp. 457–488).

W. Melzer, *Causes of the Slow Ignition of Dry Quenched Coke* (Berichte der Gesellschaft für Kohlentechnik, 1926, vol. 1, pp. 489–498).

K. Bunte, *Kindling Points and Reaction Capacities of Coking Products* (Gas World, Coking Section, June 5, 1926, vol. 84, p. 68). The kindling point is shown to depend on the size of the granules of the coke, on the velocity of the current of air, and on the oxygen content of the air current. Other experiments indicated that the kindling points and the CO_2 reaction capacities were proportional to one another.

Low-Temperature Carbonisation.—R. V. Wheeler, *The Low-Temperature Carbonisation of Coal* (Fuel Economist, June 1926, vol. 1, pp. 433–436). The technical and economic requirements of a low-temperature carbonisation process are discussed, and illustrated particulars are given of the "Pehrson" system. The particular feature of this process is that it aims at differentiating between the water-forming and oil-forming stages of the carbonisation of coal, and providing means for regulating the agglutinating properties of highly caking coals. Two intercommunicating rotary retorts are used, admitting of a continuous feed and discharge of the material heated.

W. R. Chapman, *The Parr Process of Low-Temperature Carbonisation of Coal* (Fuel, Aug. 1926, vol. 5, pp. 355–361). The principle of the Parr process consists in the introduction of a preheating treatment of the coal, the object of which is (*a*) to conserve the coking principle or binding agent of the coal and prevent its destruction by protracted heating or by contact with oxygenated gaseous compounds; (*b*) to overcome the effects of weathering or oxidation of the lignitic portion of the coal; and (*c*) to raise the charge of coal to such a temperature that the heat is rapidly distributed throughout the charge, so that

the critical stage—that is, the plastic stage—is rapidly attained and passed.

S. W. Parr, *The Constitution of Coal, having Special Reference to Problems of Carbonisation* (Industrial and Engineering Chemistry, June 1926, vol. 18, pp. 640–648). Past and present-day research on coal is reviewed, and the results of investigations are employed to give a picture and an explanation of the mechanism of the process of carbonisation.

V. Z. Caracristi, *Low-Temperature Carbonisation* (Journal of the Franklin Institute, Sept. 1926, vol. 202, pp. 323–336). The author distinguishes between low-temperature and high-temperature distillation, according to the character of the solid residues recovered. The latter process aims at the production of metallurgical coke, the recovery of volatiles being of secondary importance, whereas in the former process the low-temperature coke formed is the by-product. He discusses the factors and conditions governing the low-temperature distillation of coal, and indicates several methods of disposing of the solid residue. A long account is given of the many difficulties encountered in the development of the lead-bath process, and how they were overcome.

H. W. Brooks, *Low-Temperature Carbonisation in Europe and America* (Journal of the Franklin Institute, Sept. 1926, vol. 202, pp. 337–364). The author deplores the lack of interest in the problem of the diminishing petroleum supplies and their replacement by the products of low-temperature carbonisation. He compares the state of affairs as regards solid fuels in Europe and America, showing the differences in the problems to be faced in the two continents. He describes the "Coalite" and the Rolle vertical retorts, the McIntyre horizontal retort, the Piron tunnel kiln retort (installed by the Ford Motor Co.), the Thyssen and the "Fusion" rotary retorts, the Maclaurin internally-heated vertical retort, the Hood-Odell carboniser for American lignites, the Nielsen inclined rotary internally-heated retort, the Sutcliffe and Evans "pure coal briquette" process, and the McEwan-Runge vertical internally-heated retort for carbonising pulverised coal.

A. C. Fieldner, *The Low-Temperature Carbonisation of Coal* (Fuel, 1926, vol. 5; May, pp. 203–214; June, pp. 265–271; July, pp. 294–297). A review of the principal processes and apparatus devised for carrying out the low-temperature carbonisation of coal.

Low-Temperature Carbonisation (Electrician, 1926, vol. 96; June 18, pp. 644–645; June 25, pp. 669, 675; Fuels and Furnaces, Aug. 1916, vol. 4, pp. 915–916). A description of the Geissen process for the low-temperature carbonisation of coal. Low-grade gas is burnt in a type of Bunsen-burner, the flame being mantled by a refractory cylinder; the latter is surrounded by an iron cylinder, outside which are supported concentrically a column of rings forming a "corrugated" annular space in which the fuel (generally lignite) is contained. The burnt gases from the Bunsen-burner pass downwards between the refractory cylinder and the iron cylinder, the revolutions of the

latter and suitable gear at the bottom causing the resulting semi-coke to discharge at the bottom. Details of test runs, and a diagrammatic sketch of a plant in which a very good combination of heat economy with energy economy is attained by the interpolation of a back-pressure turbine, are given.

Carbonisation of Coal in Continuous Vertical Retorts (Department of Scientific and Industrial Research, 1926, Paper No. 15). This report is one of a series giving the results of work carried out at H.M. Fuel Research Station. In this instance the investigation was undertaken to ascertain whether continuous vertical retorts could produce good yields of gas and coke comparable in quality with that obtained from horizontal retorts. The effect on the yield of introducing steam at the base of the vertical retorts is also recorded, and experiments are described having as their object the raising of the calorific value of the gas obtained.

N. Simpkin, *Some Aspects of Low-Temperature Carbonisation* (Chemical Age, Mar. 21, 1925, vol. 12, pp. 268–270).

C. Berthelot, *Present Views on the Low-Temperature Carbonisation of Combustible Minerals* (Revue Universelle des Mines, July 1, 1926, vol. 11, pp. 29–33).

O. J. Parker, *Low-Temperature Carbonisation: The Economic Side* (Proceedings of the South Wales Institute of Engineers, 1926, No. 4, vol. 42, pp. 403–410).

N. J. Bowater, *Further Considerations of Low-Temperature Carbonisation* (Iron and Coal Trades Review, July 9, 1926, vol. 113, p. 73).

Low-Temperature Distillation of Coals (Colliery Guardian, Aug. 13, 1926, vol. 132, pp. 348–349). Illustrated particulars are given of the Crosier process plant for the treatment of coal and oil shale.

C. Ingman, *The Carbonisation Process of the Midland Coal Products, Ltd., Colwick Estates, Nottingham, and its Application to Collieries* (Transactions of the Institution of Mining Engineers, Oct. 1926, vol. 52, pp. 63–85).

G. P. Lewis, *Notes on Some Low-Temperature Tar Oils* (Fuel Economist, May 1926, vol. 1, pp. 365–367). The author shows the fractionation variation in low-temperature tar oils produced from similar coals in three distinct types of retort.

E. Parrish, *The History and Composition of Low-Temperature Tar* (Fuel, Oct. 1926, vol. 5, pp. 436–465). A review of previous investigations on the constitution and composition of low-temperature tar. Tars produced by the low-temperature carbonisation of coal showed great variations, both in their content of neutral, acid and basic compounds and in their behaviour on distillation. The impurities present, usually sulphur compounds, may represent as much as 10 per cent. of the total oils. The neutral oils form 50 to 80 per cent. of the tar, and consist of a mixture of paraffin, naphthene, aromatic and unsaturated hydro-carbons, together with oxygen and sulphur compounds. A bibliography of the literature on the subject is appended to the paper.

IV.—*LIQUID FUEL.*

Alaska.—G. C. Martin, *Petroleum in Alaska* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1173–1180). Brief particulars are given of the stratigraphy and structural geology of the oil-bearing regions of Alaska, together with descriptions of the oilfields.

Albania.—A. H. Redfield, *Petroleum in Albania* (Engineering and Mining Journal, Sept. 11, 1926, vol. 122, pp. 404–411). An account is given of those places at which indications of oil have been noted, and of the steps which have been taken to develop an industry. The general geology of the country is discussed in the light of descriptions given by recent Italian, French, and German writers. A very useful bibliography of articles bearing on the subject is appended. Two-thirds of Albania was practically unknown before the Great War; occupation of the country by various armies led directly to the study of its resources by foreign engineers. After the Armistice, keen international competition for petroleum arose, and six concessions to foreign companies were given in 1925, in October of which year the Anglo-Persian Oil Co. began drilling.

Australasia.—A. Wade, *The Search for Oil in Australia* (Journal of the Institution of Petroleum Technologists, Apr. 1926, vol. 12, pp. 145–164). The author describes his investigations made with a view to the future development of oil-bearing regions in Australia. These occur in South Australia, Western Australia, the Northern Territory, Queensland, and New South Wales. One of the finest kerosene shale deposits in the world exists to the west of Sydney, but the competition from importing companies has made it unprofitable to work it at the present time. Otherwise no oilfield has yet been developed, but there are prospects of discoveries which may prove of importance.

H. I. Jensen, *The Probable Oil Formations of North-Eastern Australia* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1254–1276). The author discusses the prospects of oil occurrences in Queensland and the Northern Territory. It is shown that Queensland possesses rocks of the right lithological nature, folded in the right manner to yield oilfields of great magnitude.

D. J. Mahony, *The Kimberley District, Western Australia* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1251–1252). The Kimberley district is the northernmost part of Western Australia. The geology of the region is imperfectly known, but the positive evidence for potential oilfields in this region is the presence of abundant bitumen (impsonite) near the junction of the Ord and Negri Rivers (east Kimberley) and traces of liquid petroleum near Mt. Wynne in the Fitzroy Valley (south-west Kimberley). Boring is in progress in

both of these areas, but reports indicate that it is not sufficiently advanced to warrant any conclusions being drawn in regard to possible results.

D. J. Mahony, *Petroleum Prospects in Victoria* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1252–1253). The geological formations are briefly dealt with, and it is concluded that no evidence is available to support the view that petroleum is likely to be found in Victoria, but much more geological investigation is required before any definite pronouncement can be made concerning its presence or absence.

E. R. Stanley, *Oil Provinces in New Guinea* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1248–1251). The author briefly describes the developments in the search for oil in New Guinea. To date no commercial petroleum has been obtained, but the indications have been, and are still, sufficient to warrant precise geological investigations of the areas most likely to yield results.

P. G. Morgan, *Petroliferous Areas of New Zealand* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1244–1247). Seepages of oil have been observed in a number of localities. In three districts the indications of petroleum are unusually strong. These are: (1) Kotuku, in North Westland; (2) New Plymouth and adjoining areas; (3) Gisborne-East Cape District.

W. H. Schneider, *The Oil Shale Industry of Tasmania* (World Power, Nov. 1926, vol. 6, pp. 271–272). The Tasmanite oil shales of Tasmania are difficult to retort, as the material is converted by heat into a fine floury dust; they are also low-grade. Small vertical retorts appear to give the best results, the temperatures being 400° C. at the top and 500° to 550° C. at the bottom, multi-draw-off pipes being fitted to prevent cracking of the distillate. Great difficulty is experienced in working the retorts; the velocity of the shale passing through the retorts is insufficient to keep the inside clean and the gases deposit carbon in the flue pipes. The recovery of oil is not very high, because the shale is only half cooked to prevent it from powdering. The crushing of the shale is another problem not yet entirely solved.

Canada.—R. W. Brock, *Petroleum Provinces of Canada* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1168–1173).

R. T. Elworthy, *Natural Gas and Petroleum in Northern Alberta* (Canada Department of Mines, Mines Branch, Investigations of Fuel and Fuel Testing, 1924, pp. 103–115). The report outlines the results of an investigation of the gas and oil resources of Northern Alberta.

Dutch East India.—H. A. Brouwer, *Oil Provinces in the Netherlands East Indies* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1280–1283). The structure of the oilfields is briefly described.

France.—R. Brunschweig, *The Petroleum Deposit at Gabian* (Chaleur et Industrie, May 1926, vol. 7, 243–248). The author describes the source of the petroleum, the geology of the neighbourhood of Gabian (France), the discovery and development of the deposits, and discusses the output of oil and its nature.

Japan.—G. Kobayashi, *An Outline of the Geology of the Oil-Fields in Japan* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1180–1206). An outline is given of the geology of the oil-bearing districts, together with special descriptions of the oilfields in Hokkaido, Akita, and Echigo.

South America.—A. H. Redfield, *The Petroliferous Systems of South America, Central America, and the West Indies* (Proceedings of the Pan-Pacific Science Congress, Australia, 1923, vol. 2, pp. 1207–1244). The author summarises present knowledge of the geologic occurrence of hydrocarbons in South America, Central America, and the West Indies, and outlines some of the geologic problems awaiting solution. A bibliography of literature on the subject is appended.

C. M. Hunter, *The Oilfields of the Maracaibo Basin* (Journal of Institution of Petroleum Technologists, June 1926, vol. 12, pp. 235–246). The development of petroleum mining in this area is described. The Maracaibo Basin in Venezuela promises to become one of the most productive oilfields of the world. The total production in 1925 was over 19 million barrels, and will exceed 30 million in 1926.

United States.—G. W. Wallace, *Development of the Shale-Oil Industry in California* (Paper presented to the American Society of Mechanical Engineers, Nov. 19, 1925: Mechanical Engineering, July 1926, vol. 48, pp. 731–738). The enormous deposits of oil shale in the United States make it probable that large quantities of oil will be produced from this source. It is only recently, however, that successful processes, analogous to the carbonisation of coal, have been developed. Particulars are given of several experimental plants; the process is described, and data of plant costs, plant yield, and oil composition are presented. In the author's opinion, a shale-oil industry can be profitably established at the present time.

W. A. English, *Geology and Oil Resources of the Puente Hills Region, Southern California* (United States Geological Survey, 1926, Bulletin 768). An account is given of the geography, geology, and oil resources of this region. The report also includes a chapter on the chemical character of the oil by P. W. Prutzman.

D. F. Hewett, *Geology and Oil and Coal Resources of the Oregon Basin, Meeteetse, and Grass Creek Basin Quadrangles, Wyoming* (United States Geological Survey, 1926, Professional Paper 145).

J. D. Sears, *Geology of the Baxter Basin Gas Field, Sweetwater County, Wyoming* (United States Geological Survey, 1926: Bulletin 781–B).

The report contains an account of the structure and extent of the field.

Origin of Oil.—M. Stuart, *Working Hypotheses in the Geological Search for Oil* (Journal of Institution of Petroleum Technologists, 1926, vol. 12, June, pp. 316–335). The author considers the theories that have been put forward concerning the origin or origins of known oil deposits, to discover whether it is possible to build up any working hypotheses for the guidance of the geologist in search of oil.

Liquefaction of Coal.—H. Nielsen, *Oil from Coal* (Gas Journal, 1926, vol. 174; June 16, pp. 591, 592; June 23, pp. 650–653; June 30, pp. 732–734). Stress is laid on the importance of the scientific utilisation of oil resources, and a comprehensive survey is made of the production of oil from coal by various processes. Conclusions are drawn as to the most suitable processes either for all-round oil production or for the special production of the various grades of light, heavy, and other oils.

H. Nielsen, *Oil from Coal* (Iron and Coal Trades Review, 1926, vol. 112; June 11, pp. 919–920; June 18, pp. 961–962; June 25, pp. 1008–1009). A comprehensive survey is given of the production of oil from coal by various processes, both English and foreign.

G. P. Lewis, *Some Results in Liquid Extraction of Coals, Lignites, &c.* (Fuel Economist, 1926, vol. 1; Feb., pp. 236–238; Apr., pp. 325–327). The author presents the results of tests on the extraction of oil from solid carbonaceous matters.

Oil Shale.—A. A. Swinnerton, *Distillation of Oil-Shale—Comparison of Laboratory Methods* (Canada, Department of Mines, Mines Branch, Investigations of Fuel and Fuel Testing, 1924, pp. 69–81). The results are given of an investigation of several laboratory methods for the examination of oil shale samples. As a simple and reliable method either the small or large field assay retort is to be preferred to any of the other methods examined.

F. Challenger, J. Haslam, R. J. Bramhall, and J. Walkden, *The Sulphur Compounds of Kimmeridge Shale Oil* (Journal of Institution of Petroleum Technologists, Apr. 1926, vol. 12, pp. 106–134). An investigation of the nature of the sulphur compounds, their identification and characterisation in the form of easily recognised derivatives as found in the Kimmeridge shale oil of Dorset.

Refining of Petroleum.—A. E. Dunstan, *Fluid Fuels* (Paper read before the Institution of Fuel Economy Engineers, Sept. 24, 1926). A discussion of the production, refining, and utilisation of liquid fuels.

The Petroleum Refineries at Pechelbronn (Chaleur et Industrie, Sept. 1926, vol. 7, pp. 487–498). A description of the works and of its products.

Combustion and Uses of Fuel Oil.—W. Kemp, *The Combustion of Fuel Oil* (Fuel Economist, Aug. 1926, vol. 1, pp. 499–504).

J. F. Barkley, *The Combustion of Fuel Oil in Power Plant Boilers* (Fuel Economist, May 1926, vol. 1, pp. 352–353).

Oil-Fuel Apparatus for Steam Boilers (Engineer, July 16, 1926, vol. 142, p. 62). Notes on oil-fuel apparatus for steam boilers. With the use of oil-fuel fire-doors boilers can be fired at will with either solid or liquid fuels. The oil is fed to the burners by gravity from a tank about 6 or 8 feet above the boiler and warmed by a steam coil. When changing over from solid to liquid fuel the grate is left covered with ashes or broken firebrick, so that an incandescent mass is already present on the grate, so preventing the inlet of too much cold air.

Fuel Oil Furnace Burners for the Forge Shop (Machinery, Oct. 28, 1926, vol. 29, pp. 108–110). The design of fuel oil burners and ignition chambers is discussed. This is a matter of considerable importance, in view of the very high flame temperature of fuel oil. Thorough mixing of the fuel oil and air is equally important, and is linked with the question of the protection of the furnace lining.

Burner Selection Involves Study of Entire Heating Problem (Iron Trade Review, Sept. 2, 1926, vol. 79, pp. 576–577). A brief discussion of the conditions governing the selection and application of burners for oil-fired industrial furnaces.

W. C. Kammerer, *Handling Fuel Oil from Car to Burner* (Forging, Stamping, Heat Treating, Sept. 1926, vol. 12, pp. 333, 334). The author sets forth briefly the factors which must be considered in unloading fuel oil from the tank car, storing it and supplying it to the burners.

V.—*ARTIFICIAL GAS.*

Gas-Producers.—J. F. Rogers and V. Windett, *Mechanical Gas-Producers* (Paper read before the American Society of Mechanical Engineers, Apr. 6, 1926: Mechanical Engineering, July 1926, vol. 48, pp. 743–746). The paper describes the necessary features which must be incorporated in mechanical gas-producers, and traces their evolution to their modern state of development. Problems arising out of the substitution of completely mechanical for hand-operated producers are discussed. The L-type Wellman-Seaver-Morgan producer is described and illustrated.

Mechanical Gas-Producers (Fuel Economist, June 1926, vol. 1, pp. 439–442). Illustrated particulars are given of the design of the Chapman gas machine and Chapman agitator. Operating results of producers fitted with this type of agitator are included.

Producer Practice.—J. A. Goff, *Chemical Reactions in the Gas-Producer* (Industrial and Engineering Chemistry, June 1926, vol, 18,

pp. 585–588). The laws of chemical equilibrium are applied to the problem of the producer. With certain assumptions as to the manner of operating the producer and the character of the fuel used, data concerning the temperature at which the producer will work continuously, the composition of the producer-gas, the thermal efficiency of the producer, and the steam-air ratio for maximum thermal efficiency may be obtained. If producer-gas is maintained in chemical equilibrium and the amount of steam introduced with the air is just sufficient to keep the producer at a constant temperature, the working of the producer under varying conditions will proceed according to the laws of chemical equilibrium and thermodynamics. The nitrogen content of the gas will increase with a rise of temperature, since the higher the temperature the less steam is required to maintain it constant. The hydrogen content reaches a maximum at about 950°, and diminishes at higher temperatures while the carbon monoxide increases to a definite maximum and then falls off. The efficiency of the producer increases up to about 1100° and then diminishes owing to sensible heat losses in the gas. For maximum efficiency approximately 0·4 lb. of steam should be used per lb. of carbon.

Ch. de la Condamine, *Study of the Equilibrium in Gas-Producers* (Chaleur et Industrie, 1926, vol. 7 ; June, pp. 343–350 ; July, pp. 402–410). The author discusses the reactions taking place in the producer and the factors governing its efficient operation, and describes some tests made on producers by engineers on the Testing Staff of the " Office Centrale de Chauffe Rationelle."

Progress in Gas-Producer Practice (Colliery Engineering, 1926, vol. 3 ; June, pp. 277–279 ; July, pp. 327–329). A discussion of the outstanding features in the design of gas-producers. Automatic charging, mechanical agitators, and automatic ash removal are dealt with.

F. S. Bloom, *Operation of Gas-Producers* (Fuels and Furnaces, Apr. 1926, vol. 4, pp. 451–452, 458). A discussion of the operation and design of jet blowers and turbo-blowers. The use of the turbo-blower is an advantage in operating the gas-producer, for it allows the quantity of moisture to be controlled. The jet blower if properly designed will supply the maximum amount of air per pound of steam that is desirable in good gas-producer practice.

F. E. Leahy, *Gas-Producer Operation* (Paper read before the Association of Iron and Steel Electrical Engineers, June 1926 : Fuels and Furnaces, July 1926, vol. 4, pp. 837–840). A discussion of the various factors that affect gas-producer operation.

C. B. Marson and J. W. Cobb, *Influence of the Ash Constituents in the Carbonisation and Gasification of Coal. Part II.—Gasification of Special Cokes in Steam* (Gas Journal, Sept. 29, 1926, vol. 175, pp. 882–891 ; Gas World, Sept. 25, 1926, vol. 85, pp. 338–340). Experiments on the gasification of coke in steam showed that, while some bodies had little or no effect on the rate of gasification or the

constitution of the gas made, other bodies, such as lime, ferric oxide, and sodium carbonate have a decided action, the effect of the last-named compound being extremely marked.

W. E. Rice, *Relative Value of Carbon Monoxide and Hydrogen as Constituents of Producer-Gas* (Fuels and Furnaces. Feb. 1926, vol. 4, pp. 151–162). The author discusses calorific values, furnace efficiencies, and flame temperatures for mixtures of carbon monoxide and hydrogen. The effect of dilution by water vapour and the action of hydrogen flame on clay refractories are also dealt with. It is shown that carbon monoxide possesses an advantage over hydrogen as a furnace fuel because of its higher net calorific value, the greater radiation from its flame, and its higher flame temperature. Hydrogen is an undesirable constituent of producer-gas because of its short flame and the deleterious action of its surface combustion on furnace walls and retorts.

J. P. Wood, *Experiments Made at the South Australian School of Mines on the Use of Lignite from Moorlands in Gas-Producers* (South Australia, Department of Mines, 1925 : Mining Review, No. 43, pp. 42–47). A description is given of experiments undertaken to determine the possibility of using brown-coal in a suction gas-producer. The results show that it is possible to run an engine with a producer on the down-draught principle, provided a water seal is included in the design, so that the clinker can be continuously removed.

Small Coke as Producer-Gas Fuel (Fuel Economist, Aug. 1926, vol. 1, pp. 525–527). The experimental results are given of an investigation carried out in Germany on the gasification of coke in producers.

H. Dupuy, *A Process and Plant for Distillation* (Chaleur et Industrie, Apr. 1926, vol. 7, pp. 183–186). The author describes a plant in which the coal is heated " internally " by means of superheated low pressure steam, the latter carrying off the products of distillation which are separated and removed, the steam circulating in a closed circuit. The heating is more rapid, regular, and economic.

Use of Gas for Industrial Heating.—G. W. Hewson, *Blast-Furnace Gas as a Fuel* (Fuel Economist, 1921, vol. 1 ; Feb., pp. 231–235 ; Mar., 283–287). The author discusses the value of the gas, gas production at the blast-furnace, the thermal inefficiency of the blast furnace, and the characteristics of the gas.

G. W. Hewson, *Blast-Furnace Gas for Steam Raising* (Fuel Economist, 1926, vol. 1, Apr., pp. 303–305 ; May, pp. 355–356). The utilisation of blast-furnace gas under boilers is dealt with, with special reference to the regulation of the air supply, and efficient mixing of the gas and air.

G. W. Hewson, *Blast-Furnace Gas as a Source of Power* (Fuel Economist, 1926, vol. 1 ; June, pp. 423–427 ; July, 477–481 ; Aug., pp. 533–539). The utilisation of blast-furnace gas in internal combustion engines and for the generation of electricity is discussed. The cleaning of the gas, the economies effected from the use of dry cleaned gas, and the Halberg-Beth system of gas cleaning are also dealt with.

J. D. Keller, *Application of Raw Producer-Gas to Sheet and Pair Furnaces* (Fuels and Furnaces, Feb. 1926, vol. 4, pp. 209–212). The use of producer-gas for the firing of sheet and pair furnaces at the plant of the McKeesport Tinplate Co., McKeesport, Pa., is described. A battery of six Chapman producers serves eighty-eight furnaces. About 6 tons of coal are gasified per hour. The gas main is 84 inches in diameter, and at each mill there is one take-off for serving one pair furnace and one sheet furnace. At proper intervals the gas main is reduced in diameter and is about 42 inches at the end mills. The furnaces are fired from the rear with one burner to each furnace. Furnace upkeep has been reduced to practically zero in so far as heating chambers are concerned, and the output has increased.

Gas-Engines.—S. Kreuzer, *Irregularities in the Running of Gas-Engines while Tapping the Blast-Furnace* (Stahl und Eisen, Sept. 23, 1926, vol. 46, pp. 1288–1290). One of the most frequent troubles in blast-furnace gas driven engines is the premature firing that is apt to occur on shutting off the blast when tapping is completed. Not only is the pressure of the gas supply altered, from 60 centimetres mercury gauge to about 10 centimetres, but the composition of the gas and consequently the calorific value change when the blast is throttled. The following table shows the composition of the gas while the metal is running, while the blast is throttled, and when quickly turned on again :

	Per Cent.					Cal. Value.
	CO_2.	CO.	CH_4.	H_2.	N_2.	
While metal runs. Pressure, 60 cm. mercury col.	6·2	31·9	0·1	2·4	59·4	1040
Blast throttled. Pressure, 10 cm. mercury col.	17·6	38·6	0	7·6	36·2	1370
Blast turned on again. Pressure, 60 cm. mercury col.	7·2	30·2	0·1	2·5	60	1000

If there is a surplus of gas the remedy is simple enough, namely, to allow some of the enriched gas to pass to the chimney through a bye-pass. Otherwise some measure must be taken to prevent the formation of hydrogen, the excess of which is the main cause of the trouble.

J. E. James and C. Cook, *The Application of the Gas-Engine to the Manufacture of Iron and Steel* (Proceedings of the Cleveland Institution of Engineers, Session 1925–26, No. 6, pp. 184–229). The authors discuss the merits of the gas-engine in its application to the economic manufacture of iron and steel, and point out the great saving effected by the successful operation of internal combustion engines. The waste-heat boiler attached to gas-engines symbolises the most efficient and constant steam-raising method of firing. A constant feed can be

maintained, and as no dust is deposited from the waste gases, no cleaning of the fire tubes is required. An ideal combination is to have the whole of the blowing power together with 50 per cent. of the generating plant operated by gas-engines, all fitted with waste-heat boilers.

H. Froitzheim, *Steam-Driven and Gas-Driven Prime Movers in Metallurgical Works* (Stahl und Eisen, June 3, 1926, vol. 46, pp. 737–742). Comparative costs are given of steam-turbine installations and gas-engine installations, and the cost of generating 1 kilowatt-hour by either system. The gas-engine plant of equal power is much more expensive than a steam plant, the cost of the two per kilowatt installed being calculated at £18 10s. and £6 5s. respectively. The cost of generating a kilowatt-hour in both cases is much the same, being somewhat under one farthing. If, however, an allowance of 15 per cent. for amortisation is made, and the cost of the plants written off after a period of years, the advantage is very much with the gas-driven plant.

H. Wolf, *Progress in Steam Power Supply in Ironworks* (Stahl und Eisen, Oct. 14, 1926, vol. 46, pp. 1385–1392). The author in a former article pointed out that whereas the gas-engine had about reached the limit of its technical development, there was a prospect of considerable improvement in steam power plant (Stahl und Eisen, July 16, 1925, vol. 45, pp. 1225-1232). This opinion was challenged by H. Froitzheim, and new arguments and data are now presented in justification of the author's statements. The great improvements in the economical use of solid fuel since the war have reduced the cost of steam raising to a point at which a kilowatt-hour can be generated at a fraction below the cost of one generated by gas-power. That being so, it is then mainly a question of deciding which is the cheaper plant to install, and in that respect the advantage is entirely on the side of the steam plant.

A. A. Raymond, *The Gas-Engines of the Maryland Plant of the Bethlehem Steel Company* (Transactions of the American Society of Mechanical Engineers, 1925, vol. 47, pp. 1009–1013). Details are given of an installation at the Sparrows Point plant of the company of eighteen large engines using blast-furnace gas. Tables show the results of tests, operating records, and the amount of total heat available from exhaust gases of blowing and generator-unit engines.

A. C. Danks, *The Gas-Engine in the Steel Industry* (Transactions of the American Society of Mechanical Engineers, 1924, vol. 46, pp. 209–222). The paper traces the development of the blast-furnace gas-driven engine as a prime mover in the steel industry, from its initial development to the present time. The problems of design that had to be solved included methods of governing, valve gear as related to gas analysis, ignition, piston troubles, corrosion due to water-cooling, &c. The results of tests are given, and precautions to be observed in testing are outlined.

Distillation of Tar.—*Remodelled Tar Distillation Plant* (Iron and Coal Trades Review, Aug. 6, 1926, vol. 113, p. 195). Particulars are

given of the arrangement of the plant at the Ashton-under-Lyne Works of the National Gas Engine Co. for the distillation of tar from producers.

Distillation of Wood.—L. F. Hawley, *Fifty Years of Wood Distillation* (Industrial and Engineering Chemistry, Sept. 1926, vol. 18, pp. 929, 930). A brief survey of the development of wood distillation since 1876.

J. Dautrebande, *The Carbonisation and Distillation of Wood* (Chaleur et Industrie, July 1926, vol. 7, pp. 381–383). The author reviews the many by-products obtainable by the distillation of wood.

Flow of Gases in Mains.—M. Laffargue, *Industrial Measurement of High Rates of Flow of Gases* (Chaleur et Industrie, Aug. 1926, vol. 7, pp. 425–428). The author discusses the general case of the computation of the volumes of flowing gases by the measurement of their velocity, which latter is obtained indirectly from observed pressure differences in two neighbouring parts of the conduit. The case when the pressure differences on either side of a diaphragm are measured is considered in more detail.

F. E. Brackett, *The Application of Kutter's Formula to Gases* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The results are given of a study of fluid friction of gases when the density throughout the duct is practically constant. Kutter's formula for the flow of water lacks the expression of the effects of density which is necessary for application to gases. The law was discovered by which the formula could be transformed so as to be applicable to other densities; the results of the transformed equation are compared with results by the Babcock formula for steam, and by the Althaus formula for gas in cast-iron pipe, and other formulæ. A detailed mathematical presentation of the determination of Kutter's constants for air and gas is presented, with a statement of general conclusions. A series of tables shows the values for pipes of various diameters with different velocities.

R. Moissonnier, *The Regulation of Flow-Meters of the Floating-Bell Type* (Chaleur et Industrie, July 1926, vol. 7, pp. 373–380). The author describes the theory upon which the construction of these meters for measuring the flow of large volumes of gases is based. At first glance the principal condition which must be fulfilled appears simple of attainment, but the author shows that other factors may easily come into play and impair the accuracy of the meter.

VI.—*COAL WASHING AND HANDLING.*

Coal Handling.—*Pneumatic Coal Conveying Plant* (Colliery Engineering, Aug. 1926, vol. 3, pp. 356–359). An illustrated account is given of the conveying plant erected at the Bestwood Colliery, near Nottingham.

Discharging Coal Trucks by Hydraulic Means (Engineering, June 18, 1926, vol. 121, p. 726). A short account (in English) of the coal-handling plant of the Compagnie Parisienne de Distribution d'Électricité, the particulars being taken from Génie Civil (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 536).

New Coal-Handling Plant at Beckton (Engineer, July 16, 1926, vol. 142, pp. 69–71). The combined equipment of cranes and conveyors will be capable, when completed, of handling 2000 tons of coal per hour, and is being erected at the Beckton Works of the Gas, Light and Coke Company.

Great Western Railway Coal-Loading Plant at Port Talbot (Engineering, Aug. 6, 1926, vol. 122, pp. 162–164, 170, and Supplement). The company handles a vast amount of coal traffic, and has introduced all-metal trucks of 20 tons capacity to deal with it. These trucks have doors at each end, and they are quickly unloaded by hydraulic mechanism, which simply tips them up end-wise. The whole plant is described in detail and illustrated with photographs and line drawings.

The New Coal-Handling Plant at Fulham Gasworks (Engineering, July 23, 1926, vol. 122, pp. 103–105). The coal is brought to the works by water; it is discharged by two travelling Toplis level-luffing cranes into a 2000-ton bunker. This has a hopper bottom, and from it the coal is moved as required by means of conveyors.

Coal Screening.—*Preparation and Classification of Anthracite* (Colliery Engineering, May 1926, vol. 3, pp. 227–229). An illustrated description is given of a plant in operation at Hamburg for screening and picking imported British anthracite coal.

T. Dowell, *New Screening Plant* (Colliery Engineering, July 1926, vol. 3, pp. 299–304). An illustrated account of the general arrangement and design of the rotary coke-screening plant recently erected at Stella Gill, Co. Durham.

Coal Washing.—A. Allen, *The "Rheolaveur" Process for Washing Coals* (Revue Universelle des Mines, Aug. 1, 1926, vol. 11, pp. 115–122). A translation into French of an article on coal-mine management. The author describes the washing process, and the results obtained in England and in Europe.

A. Grounds, *The Washing of Small Coal* (Fuel Economist, July 1926, vol. 1, pp. 483–487). An illustrated description is given of the coal-washing plant at the Weetslade Colliery, Newcastle, where "H.H. Universal" concentrator tables are installed for dealing with small coal.

W. R. Chapman and R. A. Mott, *The Cleaning of Coal* (Fuel, 1926, vol. 5; May, pp. 184–194; June, pp. 245–262; July, pp. 278–293; Aug., pp. 325–334; Sept., pp. 386–404; Oct., pp. 422–435). The authors continue their series of articles on the washing of coal. These deal seriatim with washing tests of coal, the general theory of coal washing, the development of coal-cleaning practice and early forms of

washers, and descriptions of modern washing plants and their mode of operation.

W. R. Roberts, *The Value of Improved Preparation of Bituminous Coal* (Proceedings of the Engineers' Society of Western Pennsylvania, Feb. 1926, vol. 42, pp. 1–8). The author puts forward reasons why more and more care should be taken with the preparation of coal.

M. G. Raymond, *The Modern Preparation of Coals* (Mines, Carrières et Entreprises, Dec. 1925, vol. 4, pp. 176–179). Describes the use of flotation followed by treatment in a Dorr thickener, an Oliver vacuum filter, and Ruggles-Coles rotary driers, as applied to the treatment of coals. The pyritic slimes are separated, and are themselves classified. The coals go to the coke-ovens carrying 10 per cent. water. In England lean coals are sometimes flotated in combustible oils. About 80 per cent. of the coals is obtained practically pure; they go to the ovens with about 16 per cent. of water and the resulting coke is of very good quality.

M. Sauvet, *The Flotation Washing Installation at the Anicle Mines* (Revue de l'Industrie Minérale, Aug. 15, 1926, No. 136, pp. 355–368). A description of the plant, and of the results obtained with a flotation washing plant.

M. Sauvet, *On Coal Washing* (Revue de l'Industrie Minérale, Oct. 1, 1926, No. 139, pp. 423–428). The difficulties of regulating coal-washing machines so as to obtain the best results, and the necessity for constantly altering the setting, arising out of the irregularity of composition of the coal fed into the machines, are reviewed. The author indicates the precautions that are necessary in order to feed one type of machine to the best advantage, and describes a regulating machine which automatically carries out these precautions.

C. N. Kemp, *The Application of X-Rays to the Laboratory Jig-Testing of Coal* (Proceedings of the South Wales Institute of Engineers, 1926, vol. 42, No. 4, pp. 411–437).

A. St. John, *X-Ray Studies of Coal and Coke* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). A preliminary survey of the present status of the application of X-ray methods to the study of coal is given, and the nature, properties, production, and absorption of X-rays are described. An historical summary of radioscopic work on coal is followed by descriptions of the method of radioscopic analysis of the distribution of constituents through the body of the coal and its practical application, the radioscopic control of coal washing, and the co-ordination between radioscopic analysis and ash characteristic curves. The method of diffraction analysis of the state of association of the elementary components is described, and several possible applications are suggested.

Coal Drying.—S. A. Long, *The De-Watering of Coal: Experience at Nunnery* (Gas World, Coking Section, June 5, 1926, vol. 84, pp. 69–71). Extracts from a paper read before the Midland Section of the Coke-

Oven Managers' Association, giving a description of the Carpenter centrifuge dryer, and some notes on the results obtained.

A. Grounds, *The Drying of Small Coal* (Fuel Economist, Sept. 1926, vol. 1, pp. 547–553). One of the most important factors in the de-watering and drying of small coal is the amount of fines that is left in the coal. For coals intended for by-product coking, it is usual to reduce the moisture content down to 5 to 7 per cent., and if de-watering will not reduce the moisture down to this amount, it is usual to add, after washing, dry fine coal to the mixture in order to regulate the moisture content. Several types of de-watering and drying machines are described and illustrated.

Coal Briquetting.—F. Brauneis, *The Colloid Briquetting Process* (Montanistische Rundschau, 1926, vol. 7, Sept. 1, pp. 529–530). The principle of this new method of briquetting depends on the utilisation of the colloids already present in the coal as a binding medium. By suitable preparation of the raw coal the reaction capacity of these colloids can be increased. A portion of the raw coal, say from 25 to 33 per cent., is wet ground until the mass is in a state of colloidal dispersion, and in this pasty condition it is remixed with the original portion of the coal, and the whole mass will then bind when pressed. Coals containing colloids in only a latent form and even brittle materials can be transformed by this means into a condition in which they will bind.

M. Sauvet, *On the Distribution of the Paste in Ovoid Presses* (Revue de l'Industrie Minérale, Sept. 1, 1926, No. 137, pp. 375–383). In the manufacture of ovoids (small coal briquettes) difficulties often arise which frequently appear inexplicable, and are only remedied more or less by guesswork. In this article the author throws light on the subject by considering the conditions which should govern the choice of the most suitable means of distributing the paste to the indentated rolls of various dimensions.

PRODUCTION OF IRON.

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I.—*MANUFACTURE OF PIG IRON.*

Blast-Furnace Construction.—H. M. Boylston, *The Blast-Furnace and its Auxiliaries* (Fuels and Furnaces, June 1926, vol. 4, pp. 695–700). The construction and functions of the various parts of the blast-furnace and its auxiliary equipment are discussed.

H. R. Simonds, *Make Coke Pig Iron in New England for the First Time* (Iron Trade Review, Sept. 30, 1926, vol. 79, pp. 839–841). Brief particulars are given of the new blast-furnace plant erected at Mystic Ironworks, Everett, Mass. The furnace, which is rated at 450 tons a day, is 88 feet high with a 17-foot hearth and a 20-foot 6-inch bosh. It is served by three Freyn stoves, which are equipped with Hagen automatic combustion-controlled burners. The gas is cleaned in Brassert washers.

Steel Built for Low Cost Output (Iron Age, May 20, 1926, vol. 117, pp. 1424–1426). A detailed illustrated description of the new No. 4 blast-furnace of the Inland Steel Co., Indiana. The design includes many features which simplify operation, and electrical devices are employed wherever possible to supplant manual labour. The furnace, which is provided with twelve tuyeres, is 94 feet high, and has a 20-foot diameter hearth, a 23½-foot bosh, and a 17½-foot stock line. Usual practice in the design of the top is departed from to obtain a clear operating deck. The usual column construction supporting the hoppers and bell levers is done away with, and the bleeder pipes are used for this purpose. There is also provided an outrigger carrying a 15-ton trolley, which can hoist parts and place them in position without changing the hitch. The furnace is served with four two-pass side-combustion stoves, each 25 feet in diameter and 105 feet high. The gas is cleaned in a Feld washer, and that not required for the stoves is used under boilers. Two turbo-generators of 12,500 kva. each, and five steam-driven turbo-blowers, have been installed. The same plant is also described by E. C. Barringer, *Refinements in Design*

are Found in New Inland Stack (Iron Trade Review, May 20, 1926, vol. 78, pp. 1306–1308, 1315).

Cast House Arrangement Unusual (Iron Age, May 13, 1926, vol. 117, pp. 1338–1340). The arrangement of the cast house of the No. 2 blast-furnace of the Youngstown Sheet and Tube Co., Indiana, is described and illustrated. A spur from the hot metal track extends under the cast-house roof, and is commanded by a 10-ton travelling crane. Slag is run either directly to ladles or to a granulating pit. The furnace is 95 feet in height, and has a rated capacity of 700 tons per day. It is the first large stack to be erected in America equipped with sixteen tuyeres.

Blast-Furnace Practice.—S. P. Kinney, P. H. Royster, and T. L. Joseph, *Study of the Reactions in an Iron Blast-Furnace* (United States Bureau of Mines, 1926: Reports of Investigations, Serial No. 2747). Previous study of the combustion zone of the blast-furnace, by means of a series of gas samples taken through the tuyeres across the hearths of thirteen blast-furnaces (Transactions of the American Institute of Mining and Metallurgical Engineers, 1923, vol. 69, pp. 543–584), showed that the combustion of the coke in the blast-furnace hearth is complete at a distance of 32 to 40 inches from the nose of the tuyere, measured horizontally toward the centre of the furnace. In order to determine the height at which oxygen is found in a vertical direction above the tuyeres, and to obtain comparisons with the samples taken at the experimental 5-ton furnace at Minneapolis, investigations were extended to gas sampling on a commercial furnace at a number of planes between the tuyere level and stock line. The sampling was carried out on a 300-ton furnace making foundry iron, at Holt, Alabama. The furnace was operating on Southern red and brown ores and nodules from pyrite cinder. The results of the investigation showed that the oxygen of the blast was consumed, in the process of combustion, at a point 27 inches above the centre line of the tuyeres, and the penetration of the combustion zone in a vertical direction was equivalent to that in a horizontal direction at the tuyere level. The composition of the gas across a plane 20 feet above the tuyere level was constant. The excess oxygen therein was due to reduction taking place in the bosh. As the composition of the gas at this plane was constant, the abnormal gas composition shown in the centre of the hearth near the tuyere level was a local condition. This was due to the three factors: (*a*) restricted circulation of gases in the centre of the hearth area, (*b*) so-called direct reduction, and (*c*) formation of cyanides. The uniformity of gas composition at the plane 20 feet above tuyere level did not indicate uniformity of flow. Analyses of samples at planes approximately 41, 53, and 63 feet above the tuyere level show unequal gas composition across the planes. This was due to the effect of four factors: (*a*) a difference in porosity in the stock column, (*b*) segregation of iron oxides in the outer part of the column, (*c*) unequal stock flow,

and (*d*) unequal gas flow. The results indicate that better practice with lower coke consumption might be obtained if operation could be so maintained that the gas composition on any plane higher than 20 feet above tuyere level would be uniform in carbon dioxide content, and also so maintained that carbon dioxide content of the gases would increase with distance from the hearth level. This condition will exist if the materials are so arranged in the stack that the composition of the charge is uniform throughout the column.

J. Seigle, *The Relationship between the Various Indices proposed for the Determination of the Operation of Blast-Furnaces* (*Indices of Gruner, Rocour, Mathesius, and Osann*) (Revue de l'Industrie Minérale, June 1, 1926, pp. 241–250). Many attempts have been made to indicate the degree of utilisation of coke in blast-furnaces by a single characteristic figure. Gruner studied the value of the ratio of carbon dioxide to carbon monoxide in the gases at the throat; Rocour studied the proportion of carbon "burnt at the tuyeres." Mathesius investigated the amount of carbon consumed in side reactions, while Osann considered that the amount of ore reduced indirectly by carbon monoxide was of more interest. Gruner's index can be calculated at once from an analysis of the gases at the throat; the others have a meaning which must first be defined, and this can best be done by a review of the principal reactions which may modify the composition of the current of gases in their passage from the tuyeres to the throat. The author shows which relationships are mathematically necessary between these indices and the data concerning the charge in the furnace. He also demonstrates how several of the important terms in the thermal balance may be written as functions of one or other of these indices.

R. Franchot, *Specific Efficiency of the Blast-Furnace* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926: Mining and Metallurgy, Sept. 1926, pp. 368–374). According to the author, fuel consumption expressed in pounds per ton of metal tells very little of the efficiency of blast-furnace operation. Improvement can only be effected by way of adjustment of the balance between shaft and hearth. So long as the heat demand of the hearth necessitates a production of gas carrying an excess of energy over the shaft requirement, loss of CO, solution loss and hot-top will result. By withdrawing a substantial amount of hot gas from a low level in the shaft and increasing the burden a closer balance between work and energy is to be secured. With removal of cyanide as vapour in the hot gas, and consequent saving of hearth heat now devoted to vaporisation and cyanidation of alkali accumulations, effecting *per se* an adjustment as between shaft and hearth, it would appear entirely reasonable to expect a substantial increase in production with expenditure of considerably less coke.

J. Lilot, *Calculation of the Production and Cost of Pig-Iron* (Revue Universelle des Mines, July 1, 1926, vol. 11, pp. 10–28). The author

draws up a complete balance-sheet of the operation of a blast-furnace making basic pig-iron. He derives formulæ which include all the data concerning the ores, fluxes, fuel, &c., used, and so calculates the cost of the production of the pig-iron.

F. Wüst, *The Influence of the Oxidation Reactions in the Blast Furnace Process* (Stahl und Eisen, Sept. 9, 1926, vol. 46, pp. 1213–1221).

R. Schenck, *The Equilibria of Iron, Carbon, and Oxygen* (Stahl und Eisen, May 20, 1926, vol. 46, pp. 665–682). Experiments were carried out on the equilibria set up during the interreaction of the oxides of iron, the metal and its carbide, carbon monoxide, carbon dioxide, and carbon. The equilibria of iron, carbide, methane, and oxygen were also examined. New facts concerning the process of indirect reduction of the oxides by CO were established; in particular, it was revealed that not only the pure phases Fe_2O_3 and Fe_3O_4, but also solid solutions of these in each other and in metallic iron, took part in the equilibria. Evidence of the existence of a suboxide was found; it was, however, only stable below 720° C. It follows from this that below that temperature there is another equilibrium for the oxidation-reduction reaction with CO/CO_2, and its constants were determined. The investigation of the cementation of iron by CO is complicated in most cases by the simultaneous commencement of oxidation, which renders impossible the direct determination of the Fe, Fe_3C, CO/CO_2 equilibrium. For this reason the Fe, Fe_3C, CH_4/H_2 equilibrium was measured, and the former calculated from it in order to determine the conditions for the indirect cementation of iron by CO and CH_4, and also for the direct cementation by carbon in presence of CO, CH_4, or H_2. The measurements on the equilibrium between iron and CO at and below 600° C. pointed to the probable existence of a percarbide having a much higher carbon vapour pressure than cementite and elementary carbon. The equilibrium isotherms for CO and CO_2 in presence of iron were determined at 50° intervals from 550° to 1000° C., and a space model showing the relationship between pressure, temperature, and concentration in the gaseous phase was built up. From this were constructed curves corresponding to the equilibria set up during the smelting and roasting of ores, though the influence of impurities, such as silicon, manganese, phosphorus, and sulphur, were not taken account of here.

V. Falcke and W. Fischer, *Equilibria between Carbon Monoxide, Carbon, and Carbon Dioxide, and the Reactions between Ferric Oxide and Carbon and between Carbon Monoxide and Iron* (Zeitschrift für Elektrochemie, 1926, vol. 32, pp. 194–201). The authors have carried out a series of investigations, and their conclusions confirm those of Schenck and van Royen.

A. Wagner, *Influence of the Temperature in the Blast-Furnace on the Quality of the Pig-Iron* (Stahl und Eisen, July 29, 1926, vol. 46, pp. 1005–1012). A satisfactory explanation has not yet been found to account for the varying qualities of classes of pig-iron which have

precisely the same composition. Chemical, physical, and metallographic tests on an extensive scale have been unable to prove that any fundamental difference in the properties of two pig-irons, smelted under conditions differing in no particular except that the blast temperature was higher in one case than the other, is traceable to this difference in blast temperature. It is true that regular variations in composition, particularly of the graphite percentage, are noted in pig blown with a highly heated blast. But these variations are conditioned not by the high temperature itself, but by the comparatively steep temperature gradient occurring in each blowing period—a conclusion which is opposed apparently to former observations to the effect that the form of the carbon, and therefore the quality of the pig, is dependent on the degree of the blast temperature. The heat effect of the slag also exercises a dominating influence, and in a less degree both the fusion point and composition of the slag have an effect on the amount of carbon and the form in which it separates out.

C. Zix, *Important Considerations in Old and New Methods of Blast-Furnace Working* (Stahl und Eisen, Aug. 5, 1926, vol. 46, pp. 1049–1052). A critical discussion of blast-furnace lines, and the form best suited for the regular sinking of the charge, of the amount of blast and its maintenance at constant volume in order to preserve regularity of working, and the distribution of the gases and time required for reduction, concluding with a comparison of German and American results in practice.

P. Capito, *Production of Spiegel, White and Grey Iron in the Siegerland Fifty Years Ago* (Stahl und Eisen, Oct. 14, 1926, vol. 46, pp. 1394–1397). The principal ores mined in the Siegerland are carbonate ores, limonite and specular ore. The carbonates are the most important, as they are of excellent quality; the percentage of manganic oxide ranges from 4·5 to 8, but they also contain a proportion of quartz and copper pyrites. The author gives the following account of smelting these ores fifty years ago. The ores are roasted in kilns 1·5 metres diameter and 3 metres high. For smelting, Ruhr coke with ash from 12 to 18 per cent. is used in nearly all furnaces. The furnaces are not designed for the production of any one kind of iron, but grey, white, or spiegel is smelted in the same furnace as required. Formerly when smelted with charcoal the spiegel contained 4 to 5 per cent. manganese; with coke it runs at 8 to 12 per cent. All iron with a high manganese content does not show the spiegel fracture, but it solidifies as grey iron with a coarse grain. The spiegel fracture is thought to be obtained by raising the temperature of the furnace and keeping a thin, fluid slag, so as to maintain the temperature of the metal well within certain limits. This practice applies to the carbonate ores of the Siegerland, but it by no means follows that it applies to all manganiferous ores. Many further particulars are given as to the mixing of the burden, selection of the ores for the different qualities of iron, and the slag analyses.

E. Zimmermann, *Critical Review of the Results in Practice in American Blast-Furnaces, with Special Reference to Coke Consumption* (Stahl und Eisen, June 24, 1926, vol. 46, pp. 833–839). Recent reports on blast-furnace practice in the United States are reviewed, in particular those of Brassert, Wehrheim, Bulle, and Durrer. On comparing data obtained from actual practice, it is concluded by the author that the coke consumption of American blast-furnaces, running on spiegel and also on irons low in manganese, is not in any way less than that of German blast-furnaces. The interdependence of the amount of slag and sulphur content of the burden on the one hand and the coke consumption on the other is shown, and where American furnaces have achieved low coke consumptions, this is due to working with little slag and with coke of very low sulphur content.

W. C. McKee, *Iron and Steel Scrap in Blast-Furnace Burdens* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926 : Mining and Metallurgy, Oct. 1926, pp. 435–437). The author discusses the effect of scrap in amounts varying from 2 to 15 per cent. in blast-furnace burdens on the fuel consumption and the quality of the iron produced. It is concluded that the use of scrap in the burden, if proper attention has been given to its chemical composition and physical condition, will produce high-grade iron, increase the tonnage, and reduce the coke consumption.

E. J. Yates, *Some Notes on the Production of Cylinder Pig-Iron to Fracture and Analysis* (Paper read before the Institute of British Foundrymen : Foundry Trade Journal, June 17, 1926, vol. 33, pp. 457–458). The author outlines some of the difficulties of the production of cylinder pig-iron of the following analysis : Total carbon, under 3·2 per cent., and the silicon varying between 1·2 and 3·0 per cent. The author's experience has been at the Goldendale furnaces, where furnace design, low blast temperature, and slow driving are factors responsible for the production of low-total carbon iron suited to cylinder casting manufacture. The phosphorus content of the iron is entirely dependent on the amount present in the burden, and all the phosphorus goes into the metal. The manganese content is dependent on the furnace, and is the least under control of all the elements in cylinder iron. A partial reduction only takes place, and whilst the proportion of manganese which goes into the iron remains fairly constant for open irons, a much smaller proportion passes into the iron when the furnace is comparatively cold and producing white iron. Cylinder irons are on the border-line between white and open irons, with the result that the amount of manganese varies considerably.

G. Tomarchio, *The Iron Ores Utilised in Italian Coke Blast-Furnaces* (Metallurgia Italiana, July 1926, vol. 18, pp. 294–307). There are two companies owning coke blast-furnaces in Italy ; one is the Ilva Company with three furnaces at Piombino, three at Portoferraio, and three at Bagnoli, near Naples. The Piombino furnaces have a daily capacity each of 500 tons, those at Portoferraio 350 to 400 tons,

and those at Bagnoli yield each about 400 tons daily. The other is the Società Alti-Forni e Acciaierie della Venezia Giulia, with works at Servola, Trieste, which formerly belonged to an Austrian company and were taken over by the Italian State after the war. This company owns three blast-furnaces—one of a daily capacity of 200 tons, the other two of 250 tons each. The methods of sampling and analysing the ores used at these furnaces are described. The larger part of the ores is of home origin, the sources being Elba, the Val d'Aspra, Monte Argentario (Orbetello), and Sardinia. Complete analyses of all these ores are given. Those of Monte Argentario are both manganiferous and calcareous (Fe 36, Mn 18, CaO 6·50 to 7·10 per cent.). A considerable proportion of foreign ore is imported, principally from Algeria, Morocco, Spain, Greece, Russia, and Bosnia. Of these ores also complete analyses are given, and the author concludes by giving analyses of the pig-irons produced at the works of Piombino, Bagnoli, Portoferraio, and Servola.

M. A. Pavloff, *The Smelting of Pig Iron with Raw Coal in the Urals* (Journal of the Russian Metallurgical Society, 1925, pp. 97–228; Stahl und Eisen, July 8, 1926, vol. 46, pp. 920–921). The author describes trials made in smelting pig-iron in a blast-furnace at Nishni-Tagilsk with raw coal, in place of charcoal, as hitherto customary. The coal was in lumps and had, when dried, an average analysis of:

	Per Cent.
Ash	4·57
Sulphur	0·21
Carbon	80·65
Hydrogen	3·65
Oxygen + nitrogen	10·92

The volatile constituents were 19·10 per cent. The ore was a mixture of a very rich ore with 64 to 67 per cent. iron, and a lower grade with 31·7 per cent. iron. The furnace was about 50 feet high, and the output, using raw coal, was 36 tons per twenty-four hours, or very little more than when using charcoal. The composition of the pig-iron averaged: Silicon 3·14, manganese 1·34, phosphorus 0·113, sulphur 0·032 per cent. The coal consumption was just about 1 ton per ton of pig-iron smelted during the fifteen days' trial.

E. P. Ross, *Blowing in a Blast-Furnace with Oxygen* (Mining and Metallurgy, June 1926, p. 253). Particulars are given of the use of oxygen in blowing in a blast-furnace. The furnace was filled in the usual way, coke instead of wood being used in the bottom. Live coals were distributed at each tuyere and at the iron and cinder notches. A stream of oxygen was then directed on the coals until a fire was started, the furnace being allowed to draw during the procedure. The furnace was permitted to draw for twelve hours and the blast was then turned on. When first lighting up it was found necessary to lower the bell to obtain a better draught, but after a short period the bell was closed and the gas permitted to escape through the bleeders. Steam was used

in the usual way to clear the gas mains. There was not an off-cast made in blowing, and the furnace was up to normal in a very satisfactory length of time. The furnace had been relined and thoroughly dried; therefore the bricks were hot and a fair draught obtained. When the method was tried on a cold furnace little draught was obtained, and the blast had to be put on after an interval of four to five hours, and much more oxygen was consumed than in the furnace with a hot lining. A soft spongy coke that is easily fired was used in both cases.

H. M. Boylston, *The Raw Materials of the Iron Industry* (Fuels and Furnaces, Apr. 1926, vol. 4, pp. 413–420). A discussion of the composition and uses of various iron ores, mill cinder, and scale. The beneficiation of ores, blast-furnace air supply, and the phosphorus limit in Bessemer ores and pig-iron are also dealt with.

H. M. Boylston, *Blast-Furnace Operation* (Fuels and Furnaces, July 1926, vol. 4, pp. 813–824). A study of blast-furnace operation and reactions, and classification of products.

F. Krull, *Drying Air for Blast-Furnaces with Silica-Gel* (Iron and Coal Trades Review, Aug. 6, 1926, vol. 113, pp. 191–192). An English translation of an article which appeared in Zeitschrift des Vereines Deutscher Ingenieure, July 3, 1926, vol. 70, pp. 907–910.

P. Kuhn, *Trials with a Modern Blast-Furnace Stove* (Stahl und Eisen, June 17, 1926, vol. 46, pp. 801–806). The stove was a reconstructed one at the Charlottenhütte in Niederschelden, in the Siegerland. The programme of tests aimed at determining the stove efficiency, investigating the distribution of waste gases in the checkers, the measurement of the temperatures of the bricks, blast, and waste gases, the determination of the temperature gradient, and of the heat movement in the checkers. The main result of the investigation was the discovery that only the upper third part of the checkers was performing its full duty, and that the efficiency of the lower two-thirds diminished all the way down, as the temperature of the waste gases fell. It is concluded that better efficiency could be secured by leaving the topmost third of the checkers as at present constructed, building the middle third with narrower passages and thinner partition walls, and the lower third with still narrower passages and with still thinner bricks. Stoves of large diameter should be built preferably with a central combustion shaft, as the waste gases are by this means more evenly distributed.

Blast-Furnace Gas Cleaning.—Diepschlag, *The Separation of Dust Particles from Blast-Furnace Gases* (Zeitschrift des Vereines Deutscher Ingenieure, Oct. 2, 1926, vol. 70, pp. 1324–1328). The heavier dust particles are separated by baffling the flow of gas in a vertically ascending gas current. The lighter particles are not affected by this operation. The wet method of cleaning and the dry filtering of the gases have been developed, and each of these presents its own problems, which have been solved with success. It is important that the sensible heat of blast-furnace gas burnt direct as fuel should be retained. The

conditions underlying the successful application of electric methods of cleaning are fully discussed.

H. Froitzheim, *Electric Gas-Cleaning in Large Undertakings* (Stahl und Eisen, July 15, 1926, vol. 46, pp. 941–948). The development of gas cleaning by electric methods is briefly reviewed, and the author gives a detailed description of the vertical electric filter plant installed by the Siemens Schuckert Company at the Dortmunder Union Works. The gases are passed through a field of 40,000 to 60,000 volts, produced by transforming an alternating current of 500 to 60,000 volts. The results of a number of large-scale trials show that the gases are cleaned down to 0·2 to 0·05 gramme of dust per cubic metre, and in some instances to 0·004 gramme. The cost compares very favourably with the wet and dry filtering methods.

Cleaning Blast-Furnace Gases by Electricity (Engineer, June 4, 1926, vol. 141, p. 588). A brief description of the Cottrell electrical precipitation process and plant, and notes on its application at the Duluth plant of the Minnesota Steel Company for detarring the gas from five Morgan producers, and at the Denvers Gasworks, Colorado, for removing the tar from cooled gases. Details of efficiency tests are given.

W. J. McGurty, *Gas Scrubbing in the Steel Industry* (Proceedings of the Engineers' Society of Western Pennsylvania, July 1926, vol. 42, pp. 323–329). A review of the methods of gas scrubbing applied to natural gas, coke-oven gas, producer-gas, and blast-furnace gas.

K. Hofmann, *The Oxidation of Metallic Iron and the Pyrophoricity of Dust in Blast-Furnace Gases* (Stahl und Eisen, July 8, 1926, vol. 46, pp. 916–918). The pyrophoric property of dust in the waste gases of a furnace is due to the oxidation of the very fine metallic particles such as iron and manganese, the free surfaces of which are proportionately large. By causing the particles to adhere, the pyrophoricity is at once diminished, owing to the reduced proportion of free surface. A suitable method for preventing the disturbing pyrophoric effect is to heat the dust in a reducing atmosphere, by which the particles become slightly sintered and are caused to adhere. At temperatures below 600° C. the heating must be prolonged for some hours, but above 600° less than forty-five minutes suffices to make the particles adhere, whether they consist of iron or manganese and their lower oxides.

Mixers.—*A* 1000-*Ton Wellman Metal Mixer at the Ougrée-Marihaye Works, Belgium* (Iron and Coal Trades Review, Aug. 20, 1926, vol. 113, pp 257–259; Iron Trade Review, Sept. 30, 1926, vol. 79, p. 847). The mixer is fitted with charging and pouring spouts at opposite ends and a slagging spout in the centre, which can be used for pouring if desired. The mixer can be rotated through 46° in either direction, and can be completely emptied through either the pouring or the slagging spout. The port ends are fixed to the main body and carry with them the burners, so that it is not necessary to shut off the gas when the mixer is rotated. Coke-oven gas is used as fuel, and the air is preheated in

a regenerator chamber at each end. The gas-burner is arranged so that two inclined jets of gas impinge just inside the mixer, and break into a sheet of flame on combustion with the heated air. The mixer is tilted by four hydraulic double-acting cylinders. The gas consumption is approximately 250 cubic feet per hour, at a mean pressure of from 5 to 8 inch water-pressure. The maximum fall of metal into the ladle with a full mixer is 22 feet. A considerable degree of desulphurisation of the iron takes place.

Manufacture of Ferro-Alloys.—*Large Ferro-Alloy Output in South* (Iron Age, Aug. 19, 1926, vol. 118, pp. 483–484). Brief particulars are given of the plant of the Southern Ferro-Alloys Co., Chattanooga, for the manufacture of 50 per cent. ferro-silicon. There are three open top furnaces in operation, two taking three-phase current and rated at 2400 kilowatts and 1800 kilowatts respectively, and a third on single-phase current rated at 850 kilowatts. The two larger furnaces are fitted with three electrodes each, and the smaller furnace with two electrodes. The raw materials used are high-grade silica rock (averaging about 98·5 per cent. of silica), coke breeze, and heavy steel turnings. The reduction of the silica takes place at a temperature of about 6000° F. Tapping is at intervals of one or two hours, according to the size of furnace. The yield per tap ranges from 1300 lbs. of ferro-silicon from the larger furnaces to 650 lbs. from the smaller one. The charge is run out on to sand and cast in the form of slabs, which are easily broken with a hammer when cold.

E. Schlumberger, *Rapid Physico-Chemical Methods for the Control of Electric Furnace Heats* (Chemiker-Zeitung, 1925, vol. 49, pp. 913–915). The author describes a rapid method of determining the specific gravity of the substance under examination, and from this value he computes the composition of the charge by means of curves. Graphs for ferro-silicon, ferro-aluminium, and for a mixture of calcium carbide and lime are given.

Recovery of Vanadium from Iron Ore.—Von Berging, *Possibility of Extracting Vanadium from Vanadiferous Iron Minerals* (Metall und Erz, 1925, vol. 22, pp. 219–222). In the course of the reduction of the mineral in the blast-furnace the vanadium passes almost entirely into the metal; during solidification, a vanadium-rich scoria first forms and separates from the iron before the latter solidifies. This process may be applied to basic Bessemer iron by treating it in two stages. The molten metal is first partially refined in an acid converter for three or four minutes to scorify the vanadium. At the same time silicon and titanium are oxidised, the manganese also to a large extent, the carbon a little, and the phosphorus practically not at all. The vanadiferous scoria is collected, and the metal is then charged into a basic converter and treated in the usual manner. The vanadiferous scoria is treated as an ordinary vanadium mineral.

Iron Industries of Various Countries.—E. Kinander, *Notes on Jernkontoret* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 13).

A. Johansson and A. Wahlberg, *The Development of the Swedish Iron and Steel Industry during the Last Thirty Years* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 51).

L. Nordenfelt, *Manufacture of Iron and Steel in Sweden* (Journal of the Chemical and Metallurgical Society of South Africa, 1925, vol. 25, pp. 315–328).

J. G. A. Rhodin, *Mining and Metallurgy in Sweden* (Engineer, 1926, vol. 142; Aug. 6, pp. 136–138; Aug. 13, pp. 168–170). A review of the history and modern development of mining and metallurgy in Sweden. The influence of these two industries on the political and economic life of the country is described.

C. J. Kavanagh, *Report on the Economic and Financial Conditions in Germany*, 1925–26 (London, 1926, H.M. Stationery Office: Iron and Coal Trades Review, Oct. 1, 1926, vol. 113, pp. 498–499).

J. A. Heskett, *New Zealand Iron Industry* (Proceedings of the Dominion Mining Conference: Iron and Coal Trades Review, Sept. 10, 1926, vol. 113, p. 390). Brief particulars are given of the Onakaka iron ore deposits and the plant of the Onakaka Iron and Steel Company.

History of Iron.—J. A. Mathews, *The Steel Age*, 1876 *to* 1926 (Industrial and Engineering Chemistry, Sept. 1926, vol. 18, pp. 913, 914). A brief review of the outstanding features in the history of iron and steel manufacture and use, and of the development of the industry during the last fifty years.

H. M. Boylston, *Developments in the Iron and Steel Industry* (Fuels and Furnaces, Feb. 1926, vol. 4, pp. 193–204). An historical review of the progress made in the development of processes and equipment for the manufacture of iron and steel.

II.—*BLAST-FURNACE SLAGS.*

Composition and Utilisation of Slags.—R. S. McCaffery, J. F. Oesterle, and L. Schapiro, *Composition of Iron Blast-Furnace Slags* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The paper presents the results of a study which is the continuation of that reported in a paper by McCaffery (American Iron and Steel Institute, Oct. 1924, p. 285). The authors discuss the composition and structure of the four-component system, silica-alumina-lime-magnesia, and give the names and composition of twenty-two components that may enter into slag composition, and constitutional diagrams of the system. Methods, equations, and diagrams for calculating the mineral compounds present are given,

with a table of components and equations of the tetrahedral form in which ordinary blast-furnace slags may occur, and tables of mineral composition for slags with different amounts of Al_2O_3 and MgO and for seventy-four blast-furnace slags. The log is also given of a blast-furnace that started to run off-grade iron, together with notes on the performance, remedy, and analyses of the slag.

W. G. Imhoff, *Blast-Furnace Slag Analyses* (Iron Age, 1926, vol. 118; July 22, pp. 209–210; Aug. 26, pp. 547–548; Sept. 2, pp. 612–613). The general appearance of blast-furnace slag is considered, with particular reference to the three heat-indicating elements—iron, manganese, and sulphur. The relations between temperature and chemical composition, and between basic and acid slags, are discussed, and the fifteen principles governing the interpretation of blast-furnace slags are summarised. A table is presented showing the classification of blast-furnace slags. The author deals with the same subject in *Gases Affect Fluidity of Slag* (Iron Trade Review, Sept. 9, 1926, vol. 79, pp. 647–651).

A. Guttman, *The Testing of Constancy of Volume of Broken Blast-Furnace Slag in the Ultra-Violet Rays and the Cause of Slag Disintegration* (Stahl und Eisen, Oct. 21, 1926, vol. 46, pp. 1423–1428). Microscopic analysis has been used successfully in the past in discovering the particular types of microstructure of slags characteristic of their tendency to disintegrate. But such methods have not come into general use on account of the wearisome labour of preparing sections and the time necessary for their examination. A type of lamp has however been brought out lately by the Quarzlampen Gesellschaft m.b.H., of Hanau, which emits ultra-violet rays of extreme purity, and has proved very useful for qualitative analysis. In examining slags it is not necessary to grind them small, but only to bring a lump within the range of the rays of the "quartz lamp." Stable slags under the ultra-violet rays show a uniformly dark violet or bright violet fluorescence on a freshly broken surface. If weathered, yellowish-white spots appear on a uniform ground. Slags with a tendency to disintegrate show on a freshly broken surface yellowish shining or red or cinnamon-brown spots and dots on a bright or dark violet ground. The spots vary in size or are often clustered together. Very shiny bright violet spots on a darker ground are only reflection appearances of the violet rays and are not an indication of an unstable slag, neither is the occurrence of yellow or brown dots few in number and uniformly distributed over the surface. The self-disintegration of slag is due to the change of the bi-calcium silicate from the α and β form into the γ form, which change is accompanied by an increase of 10 per cent. in volume. A microscopic examination showed that the yellowish-white or cinnamon-brown spots correspond to the γ bi-calcium silicate. To produce stable slags it is desirable to reduce the proportion of lime in the furnace burden or to replace it partly by other bases (magnesia or manganese oxide), so as to obtain the stable olivine.

B. Bogitch, *Some Experiments on the Granulation of Slags and Metals* (Revue de Métallurgie, Mémoires, Aug. 1926, vol. 23, pp. 443–445; Comptes Rendus, 1926, vol. 182, pp. 1221–1223). After a brief discussion of the ususal process of granulation and the points that arise in its application to slags and metals, the author describes the particular problem with which he was confronted. He had to granulate a manganese and iron silicate slag, melting at 1250° C.; and heated to 1500° or 1600° C. being therefore very liquid, more than a cubic metre running out in four or five minutes. This he accomplished by causing a jet of compressed air to blow upwards from the bottom of the quenching tank vertically below the slag pouring spout. The process was also applied to the granulation of metals in a case where a sufficiently high drop from the pouring spout to the water surface was not possible.

Slag for Concrete (Iron Age, May 13, 1926, vol. 117, p. 1332). Particulars are given of the specification drawn up by the Engineers' Society of Western Pennsylvania, for the use of blast-furnace slag as an aggregate for concrete.

British Standard Specification for Portland Blast-Furnace Cement (British Engineering Standards Association, Report 146, 1926).

III.—*PUDDLING AND DIRECT PROCESSES.*

Manufacture of Wrought Iron.—J. Aston, *Trend of Development in the Wrought Iron Industry* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The paper draws attention to the need of wrought iron to meet specific requirements of service. Wrought iron is defined, and the fundamental objectives in puddling a heat of iron are considered. The Danks furnace of 1870 is described, together with the Roe, Ford, Ely, and Hibbard processes of mechanical puddling. The features essential to the successful operation of mechanical puddling are outlined, and a description is given of the Aston process, which is a marked digression from usual practice.

Native Methods of Smelting Iron Ore.—J. E. Evans, *Smelting Iron in Angola* (Engineering and Mining Journal, July 31, 1926, vol. 122, pp. 179-180). A description of the smelting of iron ores as practised by the natives of the Luchaze tribe in Angola, Portuguese East Africa. The ore is an impure limonite or bog iron ore, and is self-fluxing. The charcoal, made from a hardwood tree, is of good quality, but is wastefully made into a pile; the wood is fired, and when the whole is a glowing mass water is thrown on it and the charcoal recovered. The furnace of clay is about 4 feet high and 4 feet in diameter; at the back is a ditch into which the slag, iron, and unburnt charcoal is removed after a run. A hole at the bottom of the front admits a blast of air forced in

by bellows made of wood and goatskin. The outlet from the bellows is placed near but not quite against the baked clay tuyere, so that the bellows, which have no valves, do not draw in hot gas from the furnace. During the working the temperature is tested by dropping in unknown native concoctions, leaves, &c.; the "medicine man" also takes part in the proceedings. The "bloom" weighs about 20 to 35 kilogrammes, and is reheated in a charcoal furnace and pounded till it is practically nothing but soft iron. The blacksmith's tools are extremely crude, but the resulting workmanship of the finished articles—hoes, knives, axes, spears—is exceptionally good.

Manufacture of Sponge Iron.—*Utilisation of Black Sand as an Iron Ore in California* (Engineering and Mining Journal, July 3, 1926, vol. 122, p. 14). The California State Mining Bureau is quoted as stating that black sand (magnetite) accumulated on the ocean beach near Aptos, Santa Cruz County, California, is utilised for making sponge iron, alloy steel, and briquetted magnetite. The process and plant is briefly described. After drying in an oil or gas-fired kiln the grey-black beach sand is screened to remove shell and coarse gravel and is then treated in a magnetic separator. The products are magnetite, ilmenite, and chromite. Either pure magnetite or a combination of magnetite with ilmenite or chromite is fed to a revolving electrically-heated muck-bar kiln or tube. Crude oil is sprayed into the feed end; the oil does not burn, but is immediately gasified in the hot tube, and the gases reduce the iron oxide to sponge iron, which is briquetted to muck-bar billets. Gases from the muck-bar tube are dephlegmated to remove crude oil, and the excess of CO gas is available for use under boilers or in driers. It is said that no other process will directly produce ferro-titanium.

B. Kalling and G. Lilljequist, *Theoretical Considerations on the Reduction Process, Iron Ore—Sponge Iron* (Teknisk Tidskrift (Bergsvetenskap), 1926, vol. 56, pp. 1–6, 6–14).

E. Edwin, *The Iron Sponge Problem as Solved in Norway, with Special Reference to Poor Ores* (Teknisk Tidskrift (Bergsvetenskap), 1926, vol. 56, pp. 41–52).

P. Bonnerup, *Making Sponge Iron in Australia* (Engineering and Mining Journal-Press, May 29, 1926, vol. 121, pp. 889–891). This paper formed the Presidential Address delivered before the Chemical Society of Western Australia, Session 1925–26. The sponge iron was required for use in the "metallic contact process" for treating oxidised copper minerals. A pot method of producing sponge iron, and another process using an externally heated rotating cylinder were tried, but were found unsatisfactory; scaling of the pots or cylinder was excessive and nickel steel was not available, and also it was almost impossible to maintain the necessary temperature with wood fuel, the only combustible to be had. Finally a producer or modified blast-furnace process was evolved. A proportion of ironstone and fuel were charged into a down-draught producer and the iron became reduced. Much

research was necessary to find the correct conditions for obtaining maximum reduction without fusing the iron. A mechanical grate was found to be essential, and the air supply was arranged so as to extend as much as possible the zone of reaction.

Manufacture of Electrolytic Iron.—R. H. Monk and R. J. Traill, *Electrolytic Iron from Ilmenite Ores* (Canadian Mining Journal, July 2, 1926, vol. 47, pp. 671–672). An outline is given of a process which has for its object the production of electrolytic iron and the recovery of titanium oxide for use as a pigment. The ore used contains titanium oxide 31·6 and iron 40·5 per cent. It is crushed, mixed with charcoal, and reduced in a crucible at a temperature of 900° to 950° C. to a sponge. Particulars are given of the leaching tests carried out. The leaching liquor used was a mixture of ferrous and ferric chlorides. The charge of sponge for leaching was dependent upon the amount of ferric iron in the leaching liquor, sufficient being added to cause complete reduction of all iron to the ferrous state. The presence of nickel, copper, or cobalt in the electrolyte in quantities less than 0·02 gramme per litre had no apparent effect on the deposit. Larger quantities tended to cause cracking or stripping of the deposit.

R. J. Traill and W. R. McClelland, *The Hydrometallurgical Treatment of Iron Sulphide Ores for the Production of Electrolytic Iron and the Recovery of Sulphur and other Metals as By-Products* (Canada, Department of Mines, Mines Branch: Investigations in Ore Dressing and Metallurgy, 1924, pp. 92–102). The results are given of the leaching process carried out under various conditions, and the apparatus used is described. The ore used in the roasting and subsequent leaching tests contained about 85 per cent. pyrite (41·5 per cent. iron), 4·5 per cent. chalcopyrite (1·6 per cent. copper), with a small amount of lead sulphide. The tests indicate that properly roasted pyrite leaches more rapidly than natural pyrrhotite and does not require fine grinding. The method for the purification of the electrolyte is outlined. Several depositions of iron were made. The electrolyte used was that obtained from the leaching of pyrrhotite and pyrite ores, and contained zinc and lead as impurities with a small amount of copper. The deposits obtained were dark grey in colour and somewhat pitted. The current density ranged from 101 to 105 amperes per square foot, with a cell voltage of 4 to 4·2 volts, showing a current efficiency of 88 to 90 per cent. The maximum temperature in the cell was 80° C., and the anolyte outflow ranged from 8 to 30 grammes of ferric iron per litre. Under ideal conditions and proper regulation the anolyte outflow should run about 64 per cent. ferric iron.

Production and Uses of Electrolytic Iron (Engineering and Mining Journal, Sept. 4, 1926, vol. 122, p. 372). A short account of an article by C. P. Perin in Research Narratives. The author advocates the more general use of electrolytic methods of producing iron, both for extracting iron from ores in localities far removed from fuel supplies and for

recovering scrap iron and steel. He estimates that 20 million tons of iron and steel are lost annually by corrosion, and suggests that discarded articles of iron and steel might profitably be recovered by electrolytic means. The plant of the Niagara Electrolytic Iron Co.'s works at Niagara Falls is briefly described. Iron of a purity of 99·96 per cent. is produced; the electrolyte is ferrous chloride, and the cathodes are long, thick, hollow, revolving steel cylinders with smooth surfaces. Annealing removes most of the embrittling hydrogen from the deposited iron tubes, and they are then expanded sufficiently for removal from the cathodes by a special stripping machine. The tubes are split and rolled into plates, and slit into narrow strips or coils for rods and wire-drawing. There are many uses for electrolytic iron.

W. Crafts, *Commercial Production of Carbon-Free Chromium or Ferro-Chrome by Leaching from the Ore and Electrolysis* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 175–194). Many experiments are described in which the aim was to get a reasonable amount of the chromium in the chromite used into solution. The finally evolved procedure was, briefly, to heat with a certain proportion of lamp-black or finely powdered charcoal at 1300° to 1250° C. under reducing conditions. On leaching with concentrated sulphuric acid at 100° C. a 70 per cent. yield of soluble chromium was obtained. For the production of carbon-free chromium the solution was aerated, and cleaned by the precipitation of iron, &c., by limestone, followed by concentration and electrolysis. The chromium could also be precipitated as hydroxide. For the electrolytic production of ferro-chrome the iron was left in solution, a product with 68 per cent. chromium, 32 per cent iron, and no carbon being obtained. In the anode compartment chromium could be oxidised to chromate with high efficiency.

FOUNDRY PRACTICE.

General Foundry Practice.—F. C. Thompson and M. L. Becker, *Some Notes on the Chemistry of the Cupola* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 24, 1926, vol. 33, pp. 491–495). A thermal balance-sheet is given for a typical cupola, and the reactions with carbon are discussed. The cupola should be so designed that with normal working the gases as they leave the charge should not be at a higher temperature than 400° C. The limestone added will be converted at a certain temperature into lime and carbon dioxide, and this reaction absorbs an amount of heat which is more or less equal to the whole of the heat otherwise required for the formation and heating of the slag. The substitution of lime for the unburnt limestone would remove the necessity for the provision of this heat, and the lime having a lower specific heat than the carbonate, less heat would be required for its heating to the temperature of decomposition. Although a direct economy of the order of rather more than 2 per cent. of the total coke charges would be effected by the substitution of lime for limestone, there is also an indirect effect, the degree of which it is difficult to gauge, but which may well be far more appreciable in the better combustion of the fuel to the dioxide. It is in the latter direction particularly that real economy is to be looked for. There is also one point in connection with design which would follow from the use of lime. Since the cooling effect well up in the stack would be eliminated, the height of the furnace would, for equal efficiency in so far as the temperature of the escaping gases was concerned, require to be raised. The effect of the reactivity of the coke on fuel consumption is dealt with from the point of view of cupola practice, and the supplementing of the blast by means of auxiliary tuyeres is also considered.

R. E. Wendt and J. P. Walsted, *A Study of Iron Melted in the Cupola* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The authors give the results of an investigation which show the variation in composition of iron in different parts of the same heat. It is shown that iron melts much higher up in the cupola stack than what is usually termed the melting zone. Cupola irons may be made more uniform by changing the method of charging followed by most foundries. The iron for each charge should be uniform in size, and the layers of iron to a charge should not be too large Tuyeres should be placed much higher from the sand bottom than is usually the case, so that a large body of metal may be held in the cupola before

a tap, thus allowing several charges to be melted and run together before a tap is made.

T. F. Jennings, *Melting All-Steel Charges in a Cupola Furnace* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926: Foundry Trade Journal, Oct. 21, 1926, vol. 34, pp. 353–354; Foundry, Oct. 1, 1926, vol. 54, pp. 779–780, 787). The author describes his experiences in melting steel in the cupola. It was found that a coke of not less than 90 per cent. fixed carbon and a low ash content was necessary to produce the high temperature needed, and also to reduce the amount of slag. The most suitable lining was found to be split silica brick laid against a silica block backing. The tap and slag holes were formed of silica bricks with a daubing of 75 per cent. silica sand, 2 per cent. cement, and 23 per cent. fireclay. The hearth was rammed with a mixture of silica sand and moulding sand. Steel scrap to the amount of 1650 lbs. was charged between layers of coke. The use of high grade ferro-silicon was found to be unnecessary.

H. Illies and A. Hesse-Wortmann, *Mixing Blast-Furnace and Cupola Iron* (Iron Age, Aug. 5, 1926, vol. 118, p. 350). Particulars are given of the mixers in use at a German pipe foundry. Two 25-ton mixers fired with oil-fuel have been installed. They receive metal direct from blast-furnaces and cupolas. The consumption of oil, if only hot metal is charged, is 1·8 to 2·0 per cent. of the cost, and if cold metal is added the consumption of oil reaches 3 per cent. The low consumption of oil is due to the arrangement of the burners, and to the use of a hot blast, which enters the furnace at 2190° to 2370° F. The waste gases leave the furnace at 356° to 390° F.

L. Zerzog, *New Trials in the Use of Fluorspar in Cupola Practice* (Giesserei-Zeitung, 1926, vol. 23; Sept. 15, pp. 503–508; Oct. 1, pp. 541–546). Fluorspar should always be added in the cupola if the ash content of the coke varies much, and especially if it exceeds 8 per cent.; also if the limestone contains any clay or silica, irrespective of its other constituents, which should include about 55 per cent. CaO. Fluorspar can be used with advantage to raise the temperature of the metal, if desired, without risk of overheating.

Diagrams for Calculating Cupola Mixtures (Foundry Trade Journal, Aug. 26, 1926, vol. 34, pp. 187–188). An English translation of an article by H. P. Haertel describing a method of calculating cupola mixtures (Die Giesserei, Apr. 10, 1926, vol. 13, pp. 287–289).

T. Kleinsorge, *The Determination of the Weight of the Cupola Charge as Dependent on the Shaft Diameter* (Die Giesserei, Aug. 7, 1926, vol. 13, pp. 561–562). The weight of a cubic metre of coke is generally reckoned at 450 to 500 kilogrammes, but this figure is only correct for coke stored in large chambers or bunkers. When it comes to charging a definite weight of coke into a cupola, it is found that the coke occupies a larger space than when stored in bulk, because at the sides of the shaft it lies much looser than in the centre. In fact the space occupied by the coke charge is larger, the smaller the diameter of the cupola.

In other words, the depth of the coke bed cannot safely be calculated from the diameter and weight of the charge. The author recommends that in cupola melting the same weight of coke should always be used and the weight of iron should vary according to the mixture that is being melted. For instance, in melting hard metal the weight of iron should be about $12\frac{1}{2}$ times that of the coke, and for thin castings about eight times the weight of the coke.

Calculating a Cupola Coke Charge with Reference to its Diameter (Foundry Trade Journal, Sept. 16, 1926, vol. 34, p. 246). An English summary of the above article by T. Kleinsorge.

J. R. Hyde, *Improving Cast Iron as Shown by Tests* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, July 15, 1926, vol. 34, pp. 53–55). It is shown that in practice regular cupola working, good coke and careful mixing have an improving and regularising effect on commercial cast iron. High casting temperature is always advisable for ensuring the best results in physical tests. The lowering of the total carbon content by means of special melting and steel additions has a distinctly improving effect on the metal. Cold-blast iron will often give equal tests to steel mixtures as far as the testing machine is concerned, but when applied for practical purposes the steel mixtures may be found superior, which is generally explained by the finer division of the graphite grains.

R. R. McGowan, *Determining Air Pressures in Cupolas* (Foundry, Sept. 1, 1926, vol. 54, pp. 695–696). The author presents formulæ for determining the air pressure in cupolas. A conversion table is also given for converting cubic feet of air to pounds or *vice versa*.

J. F. Francis, *The Pitot Tube and the Measurement of Cupola Volume* (Metal Industry, Sept. 10, 1926, vol. 29, pp. 247, 248). The author discusses the pitot-static tube method of measuring blast volume in a cupola, the sources of error in its use and their circumvention.

P. Dwyer, *Hot-Blast Cupola Operates in Car-Wheel Shop* (Foundry, Sept. 15, 1926, vol. 54, pp. 729–735, 754). At the foundry of the Griffin Wheel Co., Chicago, the air for the cupolas is preheated, and the method is illustrated and described. The heated and unconsumed gas is drawn from the cupola through a ring of tuyeres placed 2 feet below the charging door level. This gas is burned with the addition of a little free air under an insulated steel plate chamber containing a number of vertical cast-iron tubes. The flame travels through these tubes and heats the cold air in contact with their external surfaces. The heated blast leaves the chamber and is conveyed through a suitable pipe to a bustle pipe surrounding the cupola, which supplies a row of pendant tuyeres in the usual manner. The tubes become heated to a temperature of approximately 1000° F., and the blast enters the cupola at a temperature of between 400° and 500° F. The heated gas passes into a chamber above the tubes, and then passes out through a small stack provided for the purpose. An approximate saving of 25 per cent. in coke results from the use of preheated air.

W. Hollinderbäumer, *Foundry Furnaces* (Die Giesserei, 1926, vol. 13; July 10, pp. 493–500; July 17, pp. 513–517). After giving an historical account of the development of furnaces for melting cast iron, the author proceeds to describe the latest improvements in cupola design as carried out by Schürmann and Wüst, with notes on the practice of melting iron in these cupolas. He concludes with an illustrated description of some of the newest types of hot chambers for drying moulds.

Electric Furnace Melting of Grey Iron (Metallurgist, July 30, 1926, pp. 101, 102). An abstract in English of an article by Richards in Stahl und Eisen, Feb. 25, 1926, vol. 46, pp. 249–254 (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 557).

J. E. Fletcher, *Some Notes on Current American Foundry Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Oct. 28, 1926, vol. 34, pp. 363–366).

S. G. Smith, *Notes on Foundry Progress* (Presidential Address to the Lancashire Branch of the Institute of British Foundrymen: Foundry Trade Journal, Oct. 21, 1926, vol. 34, pp. 349–352). A survey is made of progress in foundry practice during the past fifty years.

A. Campion, *Fuel Economy in the Foundry* (Metal Industry, July 16, 1926, vol. 29, pp. 63–65). Under the two headings "Heat Generation" and "Heat Utilisation" the essentials of efficient and economical melting are discussed.

C. Irresberger, *A Jarring Forehearth to Aid Removal of Impurities in Liquid Cast Iron and Steel* (Stahl und Eisen, June 30, 1926, vol. 46, pp. 869–872). A description of the Dechesne jolting hearth. The forehearth, which is of rectangular form, is placed under the trough of a cupola or steel furnace, and when filled with molten metal is subjected to a jarring motion imparted by a rotating cam shaft passing under one end of the forehearth, the other end resting on a rocker. The greater part of the sulphur present in the cast iron goes immediately into combination with the manganese, iron sulphide forming only when the manganese is saturated. The manganese sulphide having a much lower specific weight than the iron and a higher melting point tends to rise to the top when the mass of molten metal is vigorously shaken up by the jarring motion, and there a reaction takes place according to the formula $MnS + 3O = MnO + SO_2$. The manganous oxide is taken up by the slag and the sulphur dioxide volatilises. Trials with the jarring apparatus have shown that the sulphur can be reduced by 55 per cent., and the rising up of the sulphur in the bath is proved by the fact that the surface metal is found to contain as much as 0·5 per cent. sulphur. The jarring also promotes dissolution of the graphite and decomposition of the carbide molecules, provided the metal is kept sufficiently hot. This ensures that the castings on solidification are grey iron, with a structure consisting of a pearlitic ground mass with eutectic graphite, and with small amounts of ferrite, cementite, and, in the case of phosphoric iron, steadite.

It is said that liquid steel is favourably influenced in like manner. Practical details of the use of the forehearth with the cupola are given.

C. Irresberger, *Improvement of Cast Iron by Jolting and Shaking* (Giesserei-Zeitung, July 1, 1926, vol. 23, pp. 355–358). Another illustrated description of the Dechesne jolting hearth, with micrographs comparing the structure of metal that has been jolted while liquid, with that of metal cast in the ordinary way. English translations of the articles by Irresberger have appeared elsewhere: *Improving Cast Iron by Jolting* (Foundry Trade Journal, Aug. 26, 1926, vol. 34, p. 184), *Jigger Hearth for Cast Iron* (Foundry Trade Journal, July 22, 1926, vol. 34, pp. 64–65), *Jolting Iron to Desulphurise It* (Iron Age, Aug. 12, 1926, vol. 118, pp. 413–414), *The Refinement of Cast Iron by Shaking* (Engineering, Aug. 20, 1926, vol. 122, p. 249).

O. Mäurer, *Methods for the Improvement of the Quality of Cast Iron* (Die Giesserei, Sept. 25, 1926, vol. 13, pp. 727–731). Trials with the jolting forehearth of Dechesne are described. The results show that the process yields a metal that is practically gas-free, deoxidised, dense, free of slag, and easily machineable with high tensile properties and resistance to wear.

G. A. Drysdale, *Desulphurisation of Ferrous Metals* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 557–573). The use of sodium carbonate in combination with the more vigorous alkalies, such as sodium and potassium hydroxide and other ingredients, forms a series of fluxing compounds which are being used to great advantage in the purification of iron and steel. The use of a sodium compound as a desulphuriser is dealt with, and the results are given of ladle and cupola tests.

Desulphurisation Experiments on Cast Iron (Foundry Trade Journal, May 27, 1926, vol. 33, p. 379). An English translation of an article by T. Meierling and W. Denecke which appeared in Giesserei-Zeitung, Apr. 1, 1926, vol. 23, pp. 175–178 (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 554).

Carbon and Silicon in Cast Iron (Bulletin of the British Cast Iron Research Association, July 1926, No. 13, pp. 12–13). A graph is presented which has been prepared from the formulæ developed by Ledebur and Cook for calculating the carbon and silicon contents for grey iron castings.

B. Osann, *Kish in Cast Iron* (Stahl und Eisen, Sept. 30, 1926, vol. 46, pp. 1320–1324). To study the question of the formation and effect of kish a number of trial melts were made in which the influence of the rate of cooling was particularly noted. To avoid the formation of kish it is recommended to keep the total carbon content as low as possible. Recent results of cast iron research are drawn upon in explanation of phenomena met with in everyday practice.

Making Rolls from Semi-Steel (Fonderie Moderne: Foundry Trade Journal, June 24, 1926, vol. 33, p. 474). A short account is given of melting practice for the production of rolls from semi-steel.

H. J. Young, *The Obligation of the Ironfounder to Diesel Engine Users* (Paper read before the Diesel Engine Users' Association, Oct. 15, 1926: Foundry Trade Journal, Oct. 28, 1926, vol. 34, pp. 371–373). A criticism of existing conditions in the production of cast iron for Diesel engines.

L. Scharlibbe, *The Design of Castings as it Affects Production Conditions* (Giesserei-Zeitung, 1926, vol. 23; Aug. 1, pp. 407–410; Aug. 15, pp. 449–451).

A. Lenz, *Quality in Quantities* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1924, vol. 33; June 24, pp. 481–485; vol. 34, July 8, pp. 25–30). A detailed discussion of the outstanding features in the quantity production of high-grade castings.

Chilled Cast Iron (Automobile Engineer, July 1926, vol. 16, p. 265). The nature of chill castings and the means of chilling are discussed, and some notes on the practical application of the chill and difficulties which arise are added.

Steel Foundry Practice.—R. Krieger, *Development of the German Steel Foundry Industry in the Last Twenty-Five Years* (Stahl und Eisen, 1926, vol 46; May 27, pp. 697–706; June 30, pp. 865–869). The Krieger steel foundry was established and began operations in 1900, and the author describes the development of his works and the advances made in the practice of steel casting since that date. The plant now comprises four basic open-hearth furnaces of 20 to 25 tons capacity each, and two Héroult-Lindenberg basic electric furnaces each of 6 tons capacity. Eight modern gas-producers are installed. Most of the steel foundries in Germany still use the small converter, but in the author's opinion the castings of converter steel are not of as good quality as those of open-hearth or electric steel. Many examples of heavy steel castings of complicated form are illustrated, such as bed-plates for Diesel motors, gear casings, motor casings, armature frames, autoclaves, chains, and crankshafts, and results of tensile tests of the cast steel are given.

E. Diepschlag, *The Electric Furnace in the Steel Foundry* (Giesserei-Zeitung, Sept. 1, 1926, vol. 23, pp. 474–475). The development of electric steel production in Germany and the United States is compared, and some notes are given of the current consumption and costs of production per ton of steel in a Fiat furnace.

E. T. Moore, *Electric Furnaces for Castings and Ingots* (Electric Journal, 1926, vol. 23, pp. 279–284). A description is given of the mechanical and electrical features of a furnace for the production of castings in a foundry having limited space.

Savings Result from Preheating (Iron Age, Sept. 16, 1926, vol. 118, pp. 759–762). An illustrated description of the practice at the foundry of the Industrial Steel Castings Co., Toledo, Ohio. Scrap is preheated in a bucket by means of an oil burner which is projected down through the centre of the scrap. It is brought to a temperature of 1400° to

1500° F. before being charged into the electric melting furnace. By this method the melting capacity is increased about 50 per cent. The electric annealing furnace in use is of the car bottom type, and is divided up into preheating, heating, and cooling zones. The preheating chamber is located at the side of the cooling chamber, and there is an open arch between the two so that the heat from the charge in the cooling chamber is utilised in preheating. Heating units are provided only in the heating zone. A ladle dryer of special design is also one of the features of the plant. Considerable saving in foundry sand is effected by mechanically reclaiming heap sand.

H. Malzacher, *The Straining of Steel Castings on Shrinking in the Mould* (Stahl und Eisen, July 29, 1926, vol. 46, pp. 1013–1017). General observations on the stresses set up in steel castings due to shrinkage, and the forces exerted in shrinking. The effects produced in castings and methods for reducing the trouble are discussed.

De Koenigswarter, *Method for the Study of Cast Steel Pieces* (Arts et Métiers, May 1926, vol. 79, pp. 169–178). The only fault in cast steel pieces with which the engineer must concern himself is the piping. All the others can only be cured by the foundryman; but piping, while it may be corrected to a certain extent in the foundry, is best eliminated by correct designing. The author has sought to find a graphical method of locating the fault and correcting it. In making castings one object to be aimed at is the perfectly even cooling of all the parts; any part which remains liquid longer than the rest is a probable seat of trouble. He assumes that in the period of time between the casting of the metal and its solidification a certain "zone" of the refractory mould material will be heated to the temperature of the metal, the thickness of the zone being proportioned to the volume of metal heating it. This concept enables him to show graphically where any accumulation of heat is likely to occur; knowledge on this point permits of the modification of the design where necessary, and of the placing of the feeder head or heads, and chills, in the most suitable positions.

R. A. Bull, *Steel-Foundry Management* (Transactions of the American Society of Mechanical Engineers, 1925, vol. 47, pp. 63–79). Presents a brief analysis of the industry, explaining its technical and commercial divisions, and the significance of each from the standpoint of output. The complex nature of the operations for which a manager is responsible is explained. Reasons are given for certain classifications, and policies governing staff departments are discussed. The subject of compensation for workmen and foremen is emphasised, as the author considers this a very significant detail of management.

Moulding Sands.—R. Lemoine, *The Practical Utilisation of Apparatus for Measuring the Permeability and Cohesion of Moulding Sands* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 17, 1926, vol. 33, pp. 449–452). A consideration of the methods adopted by the American Foundrymen's Association for

determining the permeability and cohesion of moulding sands at ordinary temperature. The subject is discussed under the following headings: (1) Control of the mixtures, preparation, the addition of clay to sand mixtures; (2) controlling raw materials; (3) controlling prepared sand. Apparatus for measuring permeability and cohesion in the cold state, when employed according to certain methods, may be of great service in the foundry. They enable the best way of utilising the products to be determined, and the uniformity of such products to be controlled day by day with a view to obtaining uniformity of results in manufacture.

C. M. Nevin, *The Life of Moulding Sands* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 763–791). The paper opens with a review of the important factors that might affect the durability of a moulding sand. The structure of the bond, and present methods of determining the amount of colloids in moulding sands are also considered. The results are given of tests on American sands showing the effect of heat-treatment, and a comparison is made of the bar and compression methods for determining durability. The relation between dehydration and rehydration of the bond to its durability is also discussed. The amount of the bonding material and the colloidal condition of moulding sands are important factors affecting its life. The casting method of testing the life closely approaches foundry practice and is considered the best means of determining comparative durability. As a rule permeability increases with the heat-treatment of the sand due to the formation of compound grains. Compression tests lead to practically the same conclusions as the bar tests, when used on a series of heat-treated sands. Determining comparative durability by heating the sand to 600° C. and getting the loss of strength is not a satisfactory method in its present form. Dehydration and rehydration, when carefully determined give a fairly good idea of comparative durability and might be used as a laboratory method.

T. C. Adams, *Strength Tests of Foundry Sands* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). In the first part of the paper the relation of strength tests to other foundry sand tests, the value of strength tests, principles to be observed in formulating standard strength tests, and the different problems encountered in strength testing are discussed. The second part of the paper is devoted to a description of the different methods and apparatus for making strength tests of foundry sands. The tests dealt with are tensile, compressive and transverse tests of moulding, core and other foundry sands.

H. W. Dietert and H. W. Wakefield, *Sand Control in the Foundry* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The authors describe the improvements in sand control machines and the developments incorporated in sand control tests at the plant of the United States Radiator Corporation, Detroit.

L. B. Thomas, *Metallurgical Control of Foundry Sands* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author discusses the composition of moulding sand and gives a brief outline of the chemical and physical properties. The temperature of the metal is discussed, and it is shown how the higher temperatures will destroy the bonding property of sand. A simple method of grading sands by the fineness test, and shop tests to determine the durability and refractoriness of moulding sands in conjunction with laboratory tests are described.

A. V. Leun, *The Effect of Mulling on the Physical Properties of Foundry Sands* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author has studied the effects of mulling on the properties of sands ranging from fine to coarse. In the majority of cases, increasing the time of mulling will increase the permeability of sand. With increased mulling the tensile and compressive strength will increase. The coarseness of the sand and the clay content will not vary to any great extent with prolonged mulling. However, if the sand is mulled too dry the decrease in fine material and clay will be more noticeable than when sufficient water is added to the sand.

C. A. Hansen, *The Grading of Moulding Sands* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The character of the distribution of grain size in moulding sands is analysed and described. A simple method of determining the average fineness of grain is proposed as a basis for grading sands in respect to fineness of grain. The relation between this proposed fineness scale and the grade numbers assigned by commercial sand producers in the Albany district is analysed. The relations between fineness of grain, as determined by the proposed method, and various physical properties of sands are discussed.

M. Sklovsky, *A Method of Treating and Handling of Moulding Sand* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 708–720). A description of the methods in use at an American plant, where the sand handling equipment is mechanically operated.

J. G. A. Skerl, *Permeability of Moulding Sands* (Bulletin of the British Cast Iron Research Association, Oct. 1926, No. 14, pp. 20–23).

J. E. Fletcher, *Notes on Moulding Sands* (Bulletin of the British Cast Iron Research Association, Oct. 1926, No. 14, pp. 3–7). There is difficulty in comparing results of sieve tests of different investigators owing to the variation in sieve sizes and types. The Institution of Mining and Metallurgy have issued standard sizes which are generally adopted in this country, in which the diameter of the wire is equal to the diameter of the aperture. The Bureau of Standards has also issued standards which vary slightly from I.M.M. sizes. A diagram is given in which the sizes of aperture of sieves (in millimetres) of the

U.S.A., I.M.M., and old British Standards are plotted above the sieve numbers (meshes per linear inch). The screens advocated by Rittinger are also included in the diagram.

Moulding Sand (Automobile Engineer, May 1926, vol. 16, p. 176). The essential requirements of a good moulding sand as regards texture and composition are briefly reviewed, with notes on some causes of trouble.

H. L. Campbell, *A Standard Sand for Use in Testing Core Binders* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The results are given of an investigation carried out to establish a specification for sand which could be recommended for general use in testing core binders. The effect of grain-size on dry bond and permeability was determined. It is concluded that sand for testing purposes should be limited to one sieve size. The predominating grain-size of the sand most extensively used for core making passes a 60-mesh sieve (size of opening, 0·0098 inch) and is retained on a 70-mesh sieve (size of opening, 0·0083 inch). This size of sand is recommended for use in testing core binders.

H. L. Campbell, *Methods for Determining the Properties of Cores made with Cereal Binders* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926; Foundry Trade Journal, Oct. 14, 1926, vol. 34, pp. 327–329). The most satisfactory method for determining the values of green bond in core sand mixtures consists of forcing a cone of definite shape into a core of standard size and measuring the load required to displace a given volume of the core body. The action of the cone is to disrupt the sand particles and thereby separate the core into two or more parts. The construction of the green bond testing machine is described. The method and apparatus for measuring the permeability of dry sand cores are also given, together with results of both tests.

H. L. Campbell, *The Qualities of Commercial Core Oils* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 72–84). Commercial core oils are prepared from so many different drying oils and other materials having various chemical and physical properties, that it is impossible to establish the value of an oil as a core binder on the basis of any chemical or physical property. The bonding properties of core oils may be determined accurately by making test cores in a uniform manner, baking these cores under definite conditions and measuring the transverse strength of the cores. The economic use of a specific core oil is possible only when the characteristics of that oil are known and the baking practice is controlled so that the maximum binding effect of the oil is obtained. The properties of twenty-three core oils are tabulated, and the results are given of tests showing the effect of baking temperature on strength of cores.

C. A. Hansen, *Some Properties of Core Oils* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). Five commercial pure vegetable oils, linseed, tung or China-wood, soy bean,

corn and cotton-seed, were studied in respect to the maximum core strengths developed with varying oil ratios, in respect to the baking time required to attain maximum strength at varying temperatures, and in respect to the effect of moisture on the strength of baked cores. The effects of various dryers, of various diluents, of varying proportions of rosin, of boiling the oils and oil mixtures were also studied.

R. F. Harrington, A. S. Wright, and M. A. Hoser, *Practical and Technical Data Obtained from the Use of Clay Bond in Moulding Sand Heaps* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The authors present the results of an investigation of the use of clay as a binder in moulding sand heaps. The effects of different methods of mixing, such as hand, mulling, paddle-wheel, and automatic sand cutters, are considered. An appreciable saving is effected by the use of clay and excellent castings are produced. The clay should be added in small percentages and the heap intimately and uniformly mixed. Proper venting is of great importance.

P. Dwyer, *Can Used Sand be Reclaimed?* (Foundry, 1926, vol. 54 ; Mar. 1, pp. 170–172, 187 ; Mar. 15, pp. 216–219 ; Apr. 1, pp. 265–267 ; Apr. 15, pp. 311–313 ; May 1, pp. 356–358 ; May 15, pp. 394–398). A series of articles on the general sand situation in American foundries. The topics discussed are as follows : Varieties of sand, lack of definite standards, use of clay in car wheel foundry, cost of sand, typical deposits, freight rates, variations shown in proportion of sand to weight of finished castings, mechanical testing and control methods, relative proportion of foundries in which sand control is exercised and manner in which new sand is added, and equipment and methods for reclaiming sand by addition of clay.

H. Behrens, *A New Type of Sand-Dressing Machine* (Die Giesserei, June 5, 1926, vol. 13, pp. 413–416). An illustrated description is given of an improved type of sand-dressing machine which will satisfactorily mix moist sand fresh from the pit and convert it into a thoroughly well-mixed loose moulding sand. The hourly output is about 5 cubic metres, with a consumption of 7 horse-power. The machine also treats used moulding sand and core sand by mixing and loosening them, and its efficiency is said to exceed any other type of sand-mixing machine hitherto in use.

R. A. Fiske, *Sand Handling System Yields Economies* (Iron Age, Sept. 9, 1926, vol. 118, pp. 703–705). An illustrated description of the equipment for handling and distributing sand in an American steel foundry. With the use of the equipment labour and floor space have been saved and production speeded up.

Sand Supplied Continuously (Foundry, May 1, 1926, vol. 54, pp. 346–350, 372). Illustrated details are given of the sand preparation and mould-conveying plant at the foundry of the Packard Motor Car Co., Detroit.

Reclaiming Metals Magnetically (Foundry Trade Journal, June 10, 1926, vol. 33, p. 409). Illustrated particulars are given of types of

magnetic separators suitable for the recovery of metal from foundry sand.

C. H. S. Tupholme, *Magnetic Separator Pulleys in Foundries* (Foundry Trade Journal, July 22, 1926, vol. 34, pp. 76–77). Particulars are given of a type of magnetic separator pulley suitable for foundries, for removing iron and steel particles from non-ferrous metals, and for the removal of metals from sand.

Moulding Practice.—C. Geiger, *The Travelling Turntable Moulding Machine* (Stahl und Eisen, June 30, 1926, vol. 46, pp. 872–874). The author describes and illustrates a new travelling turntable moulding machine operated by compressed air and working with simple pattern plates.

Machine Moulding with Single Flask (Iron Age, Sept. 2, 1926, vol. 118, pp. 604–606). An illustrated description of the "Wood Process" moulding machine for the production of moulds for ashpit castings. The outstanding feature is that the flask is attached permanently to the right-hand or cope unit of the machine, and is the only flask used in the moulding operation. Aluminium pattern parts are also used. The use of pouring jackets is another feature. The jackets are slipped over the moulds to support and confine the sand, and are secured to the bottom board by hinged clamps. The jackets eliminate the use of separate weights and, being of grill construction, permit the ready escape of gas.

H. N. Tuttle, *Mounting Patterns require Varied Ingenuity* (Foundry, 1926, vol. 54; June 1, pp. 438–441; June 15, pp. 479–482; July 1, pp. 521–522). Patterns are classified into three general types: match-plate patterns, rockover machine patterns, and stripping-plate patterns. The various methods of mounting patterns are described in detail.

J. Dean, *Some Notes on Machine and Plate Moulding Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, Apr. 29, 1926, vol. 33, p. 336).

E. Ronceray, *Pattern Plates* (Paper read before the Czecho-Slovakian Foundrymen's Association: Foundry Trade Journal, July 29, 1926, vol. 34, pp. 89–92). A detailed illustrated description of the processes and operations involved in the production of pattern plates for machine moulding.

F. Freytag, *Pattern Plates and their Manipulation in Conjunction with Moulding Machines* (Giesserei-Zeitung, May 1, 1926, vol. 23, pp. 231–243).

R. W. Kemlo, *Pattern-Making and its Relation to Design and Foundry Practice* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, May 20, 1926, vol. 33, pp. 349–354).

H. A. Schwartz, *Permanent Moulds for Making Iron Castings* (Paper read before the American Society of Mechanical Engineers, May 21, 1926: Mechanical Engineering, Sept. 1926, vol. 48, pp. 916–918). After a brief review of other methods that had been tried in order to make practicable the use of permanent moulds for the higher melting-

point metals the author describes his own process. In this, certain (unspecified) oils are caused to circulate through cavities surrounding the mould, thereby cooling the mould walls and maintaining a steady mould-temperature, thermostatic control of valves being employed to increase or check the flow of oil to the various parts of the mould exterior as needed. The process is intended for repetition work. Castings up to 35 lbs. in weight have been made; the mould takes five to ten seconds to fill, the casting is ready to be ejected in from ten to twenty seconds, and the mould is prepared for re-use, if no cores are to be set, in under thirty seconds.

R. Moldenke, *Permanent and Long-Life Moulds* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author summarises the position of the permanent and long-life mould in the foundry industry. The economical aspects of the developments are discussed, together with the utility of permanent moulds. Possible mould materials and the trend of experimental work are reviewed.

H. M. Boylston, *The Grey Iron Foundry* (Fuels and Furnaces, Aug. 1926, vol. 4, pp. 905–910). A general discussion on pattern design, moulding, moulding sands and facings, chilled moulds, cores, and construction and operation of melting furnaces.

Runners (Foundry Trade Journal, Aug. 19, 1926, vol. 34, pp. 162–163). A brief discussion of the outstanding features in the design and preparation of runners and runner basins for castings.

E. Ronceray, *The Moulding of Grooved Pulleys* (Paper read before the Association Technique de Fonderie: Foundry Trade Journal, 1926, vol. 33; May 27, pp. 367–368; June 3, pp. 393–395). A detailed description of the operations involved in the various methods of moulding grooved pulleys.

Moulding a Still in Loam (Foundry Trade Journal, Apr. 29, 1926, vol. 33, pp. 337–338). A brief description is given of the operations involved in the moulding of stills. The making of the core and the assembly of the mould are described.

J. G. Fitzpatrick, *Making a Pattern for a 14 Inch Double Helical Roll Pinion* (Foundry, June 15, 1926, vol. 54, pp. 469–471).

Large Castings used in Building Paper-Mill Machines (Foundry, June 15, 1926, vol. 54, pp. 456–460). Illustrated particulars are given of moulding practice for the production of castings used in paper-making machinery. Some of the moulds and cores are over 20 feet in height.

Wagner and Koch, *The Heat Economy of Mould Drying Appliances in Foundries* (Die Giesserei, Aug. 28, 1926, vol. 13, pp. 609–628). Prizes for the best papers on the efficiency and economy of mould drying chambers were offered by the Association of German Iron Founders, and the first prize of 1000 marks was awarded to the authors of this paper. After reviewing the literature on the subject of drying moulds, the systems in general use are criticised, and it is shown how defects in arrangement and design might be remedied. In general, the efficiency

of drying chambers is very low, often only 20 per cent., and in some cases 10 per cent. The radiation losses appear to be the chief source of waste; they are generally assumed to be about 42 per cent., but tests have shown them to amount to 56 per cent. Various improved methods of heating the chambers are described, the most economical being apparently gas-burners using air-blast. The cost works out at 0·16 to 0·20 shilling per square metre of mould surface dried. There is the further advantage that there is no deposit of residues from combustion, and the mould can be put in the chamber and withdrawn ready for casting and filled while still hot. The moulds are not so liable to damage by a high temperature as is usually thought, but they should be withdrawn immediately they are dried to avoid burning.

E. Sommer, *The Heat Economy of Mould Drying Appliances* (Die Giesserei, Aug. 28, 1926, vol. 13, pp. 628–634). To this paper was awarded the second prize in the competition. The author calculates the heat balances of several drying installations and discusses the factors to be taken into account in estimating the efficiency of drying chambers.

W. Schultze, *The Drying of Moulds, with Special Reference to the Maximum Permissible Temperature* (Die Giesserei, Aug. 28, 1926, vol. 13, pp. 634–647). The third prize in the competition was awarded to this paper. The results of trials as to the speed of drying showed that a saving in cost and time was effected by employing a high initial temperature, and that a high degree of saturation of the air passing off was necessary. Tests made at temperature intervals of 100° up to 800° showed that the resistance of the mould to compression rises with the temperature, that the permeability in general increases as the temperature rises, and that the effect of the drying temperature on the quality of the surface is quite inconsiderable. Any surface change of a definite character was not detected. A higher initial temperature certainly leads to considerable economy in fuel and time.

Schlipkoeter, *The Heat Conditions of a Core Drying Stove* (Die Giesserei, Aug. 28, 1926, vol. 13, pp. 648–650). The fourth prize was awarded to this paper. From the trials described it is concluded that the maintenance of an intensive air circulation is more important than keeping a high temperature in the closed stove. Blast-furnace gas was the heating agent, and although the cores were packed in tiers, those in the upper tiers did not absorb the moisture given off by the lower ones, the temperature of the heating gases being above the dew point, and the steam being superheated. The arrangement of heating showed an economy of 30 to 40 per cent. over the older one.

Borissow, *Thermal Investigation of the Core Drying Plant at the Foundry of Carl Schenck, Darmstadt* (Die Giesserei, Aug. 28, 1926, vol. 13, pp. 650–662). This paper received the award of the fifth prize. The author describes a long series of trials to determine the thermal efficiency and heat economy of a modern installation of stoves for core drying.

O. Weyer, *The Drying of Moulds* (Die Giesserei, Sept. 18, 1926,

vol. 13, pp. 709–710). The use of a portable drying stove is advocated, which runs on wheels and can be brought up to the moulds, instead of transporting them all to the stationary drying chamber. From the portable stove a blast of hot dry air is directed through the mould and dries it uniformly and quickly.

Erbreich, *Report on Drying Apparatus at Present in Use for Moulds for Iron and Steel Castings* (Die Giesserei, Oct. 2, 1926, vol. 13, pp. 741–747). Describes a number of trials made to determine the efficiency of drying stoves in use at the present day for the drying of moulds and cores. An English abstract of the above has appeared in Foundry Trade Journal, Sept. 2, 1926, vol. 34, p. 199.

A. B. McKechnie, *Industrial Heating by Oil Circulation* (Fuels and Furnaces, Mar. 1926, vol. 4, pp. 353–354). Transmission of heat by oil circulation is applicable to heating processes where temperatures in excess of those obtainable by steam are desired. The oil is heated in a central heating unit and transferred to the drying or baking oven by means of pipes. Temperatures up to 550° F. are reached without difficulty. An outline of the system is given.

I. S. Wishoski, *Baking of Radiator Cores in Oil-Fired Ovens* (Fuels and Furnaces, Sept. 1926, vol. 4, pp. 1077–1079, 1086). A description of the core department of the American Radiator Co., Buffalo. Car type ovens are arranged in two batteries of five ovens each, and are individually heated by single oil burners firing into long combustion chambers beneath the ovens. Very uniformly baked cores are produced and good fuel economy is obtained.

Centrifugal Casting.—J. E. Hurst, *Some Notes on the Development of the Centrifugal Casting Process in Great Britain and Europe* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author traces the early development of the centrifugal casting process from 1809. The application of the process to the production of pipes by the De Lavaud system and other processes is discussed. Special mention is made of the Hurst-Ball system, which is being developed, and has already been used to produce pipes 35 inches in diameter. The development of the centrifugal casting process for the production of steel and non-ferrous castings and its application to the lining of pipes with concrete and other materials are also dealt with.

L. Cammen, *Centrifugal Tube Casting in Hot Moulds* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The use of a hot mould for the centrifugal casting of small diameter tubes is a necessity. The metal will not flow in a mould that is merely warm, and when delivered against the wall of the mould it forms a thin tubular shell which immediately contracts on cooling, with the result that the tube lies loose in the mould. This condition is aggravated by the expansion of the mould by contact with the hot metal and the cast tube cracks as a result of centrifugal stresses. The requirements of a metal for hot moulds are considered. It should be non-scaling, and should

retain its full hardness and mechanical strength at temperatures of 1300° to 1600° F. The coefficient of contraction of the mould metal must not be higher than that of the cast tube. In experiments to develop a mould material a method was found for melting tungsten without oxidation, but the small outputs rendered it impossible to make moulds on a commercial scale. A process similar to calorising was also tried, and while certain properties were imparted to the steel the melting point of the metal was not affected to any appreciable extent. A method was also developed for creating on the inside of a low carbon steel or wrought iron a lining consisting essentially of tungsten, chromium, and iron. It has not been possible to line tubes larger than 6 inches in diameter and 36 inches in length, but while the manufacturing details remain to be worked out, the problem is considered to be solved in its essential features. All hot moulds have to be protected from the solvent action of the molten steel, and the methods of doing this are touched upon by the author.

Centrifugal Pipe from Sand Moulds (Iron Age, Apr. 15, 1926, vol. 117, pp. 1055–1060; Foundry, May 1, 1926, vol. 54, pp. 351–353, 363; Foundry Trade Journal, July 15, 1926, vol. 34, pp. 45–52). An illustrated description of the lay-out of the plant and the methods used for the production of centrifugally cast pipe at the plant of the American Cast Iron Pipe Co., Birmingham, Alabama. Red loam moulding sand and washed silica sand, faced with ordinary pipe foundry facing, are used for the refractory moulds. The sand is rammed in cast-iron flasks, which are placed in horizontal casting machines for pouring. After pouring the flasks are removed from the casting machines and stripped, the pipes being passed through cooling ovens before cleaning and dipping in tar, and the empty flasks are returned to the ramming station. The sand is reclaimed and treated for use again. The plant has a nominal capacity of 50,000 feet of pipe per day.

E. C. Kreutzberg, *Opens Pipe Foundry in East* (Iron Trade Review, 1926, vol. 79; Sept. 16, pp. 724–726; Sept. 23, pp. 779–781). An illustrated description of the plant and methods of the United States Cast Iron Pipe and Foundry Co., Birmingham, Alabama, where the De Lavaud centrifugal process is used for the production of cast-iron pipe. Eight casting machines are installed, driven by direct-current motors instead of the Pelton wheel.

Centrifugal Casting and its Problems [*Die-Casting*] (Iron Age, Aug. 26, 1926, vol. 118, pp. 548–550). A lengthy abstract in English of a paper on die-casting by L. Frommer, which appeared in Zeitschrift für Metallkunde, Aug., Sept. 1925, vol. 17, pp. 245–250, 289–293. Throughout the translation the term "centrifugal casting" has been wrongly used for the German word *spritzguss* ("die-casting").

Cylinder Liners (Automobile Engineer, Aug. 1926, vol. 16, p. 298). Some notes on cast-iron liners produced by the centrifugal casting process, which gives a uniform metal with an exceptionally close-grained, dense structure, and a very diminutive formation of the graphite plates. The

metal is harder than ordinary cast-iron owing to the chilling action of the hot metal dies into which it is cast, and is also tougher. Growth of the liners under varying temperature conditions is negligible, and there is no distortion as is the case with steel liners.

Defects in Castings.—*Reducing Machining Costs on Steel Castings* (Machinery, Apr. 29, 1926, vol. 28, pp. 140, 141). A short note on a report issued by the American Electric Steel Founders' Research Group. The causes of high machining costs are enumerated; some are due to bad cleaning of the castings, while others—such as cavities, blowholes, badly shaped cored holes, &c.—originate in the moulding shops or foundry.

R. S. Munson, *Defects in Steel Castings in the Foundry* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author discusses those defects in steel castings which are evident in the foundry during production.

J. M. Sampson, *Defects in Steel Castings discovered after Shipment from the Foundry* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). An analysis is made of the rejections and salvaging work in the machine shops of the Schenectady plant of the General Electric Co.

F. J. Stanley, *Defects Hiding in Steel Castings* (Paper read before the Electric Steel Founders' Research Group: Iron Age, July 1, 1926, vol. 118, pp. 12–13, 60–62). The author outlines the types of defects met with in steel castings and discusses means for their prevention. Porosity, shrinkage, blowholes, cracks, and other faults are considered.

H. S. Newton, *Scabs: Their Cause and Remedy* (Foundry Trade Journal, Aug. 19, 1926, vol. 34, p. 167). A brief discussion of the cause of scabs on castings and their prevention.

Foundry Equipment.—G. A. Geipel, *Modern Charging Appliances for Cupolas in Connection with Overhead Electric Conveyors* (Stahl und Eisen, Sept. 30, 1926, vol. 46, pp. 1324–1326). An illustrated description of modern methods for the mechanical charging of cupola furnaces.

Foundry Skip Hoist Saves Six Men (Iron Age, July 15, 1926, vol. 118, pp. 139–141). An illustrated description of the method adopted at the Detroit foundry of the Griffin Wheel Co. for the charging of cupolas. The charging equipment is a modification of the skip hoist, the skip bucket being replaced by a platform on which the charging cars are locked in place. The height of the hoist or the travel is approximately 46 feet. The platform is hoisted at a maximum speed of 75 feet per minute. Hoisting is effected by a 40 horse-power slip ring motor driving a drum 30 inches in diameter, geared down to the proper speed through heavy cast steel gears.

The International Foundry Trades Exhibition (Engineering, 1926, vol. 121; June 11, pp. 688–691; June 18, pp. 720–723; June 25, pp. 753–755; Metal Industry, 1926, vol. 28, June 25, pp. 598–611;

vol. 29, July 2, pp. 10–13). Descriptions of many of the machines on view at the exhibition are given.

The Malleable Iron Foundries of Thos. L. Hale (Tipton), Ltd. (Foundry Trade Journal, Sept. 23, 1926, vol. 34, pp. 261–264). Illustrated particulars are given of the plant and practice at these works for the manufacture of malleable castings.

Plate Foundry at Thorncliffe Ironworks (Iron and Coal Trades Review, July 9, 1926, vol. 113, p. 49). A brief account is given of the foundry equipment of Newton, Chambers & Co., Ltd., for the production of cast-iron plates.

P. Dwyer, *How New Equipment helped Triple Output in an Auto-Foundry* (Foundry, June 1, 1926, vol. 54, pp. 418–422, 444). *Costs Show Lower Trend on Installing New Foundry Equipment* (Foundry, June 15, 1926, vol. 54, pp. 464–468, 478). *Large Tonnage Handled with Ease and Speed* (Foundry, Aug. 1, 1926, vol. 54, pp. 596–600). *Produce Core by Thousands with Watch-Making Accuracy* (Foundry, Aug. 15, 1926, vol. 54, pp. 638–642). A series of articles describing the layout, equipment, and practice at the Central Foundry of the Saginaw Products Co., Michigan.

R. A. Fiske, *First Ingot Mould Foundry in West* (Iron Age, June 10, 1926, vol. 117, pp. 1642–1644). A description of methods employed in a recently completed foundry at South Chicago, Illinois, for the moulding and casting of ingot moulds. Hot metal from adjacent blast-furnaces is used, and the moulds are bottom poured. The same plant is described in the following article, *Ingot Mould Plant Starts Operation* (Iron Trade Review, June 10, 1926, vol. 78, pp. 1499–1501).

B. Finnie, *Air Furnace has Underfeed Stoker* (Iron Age, Apr. 22, 1926, vol. 117, pp. 1119–1123). An illustrated description of the plant of the Berryhill Malleable Iron Co., Evansville, Indiana. The air furnace, which has a capacity of 15 tons, is of the reverberatory type, and is fired automatically by an underfeed stoker. An outstanding feature of the plant is the design of the three annealing ovens. Each oven has two fire-boxes, one at the side and one at the front, in order to give more uniform heat. The flues are built in the side walls. Each oven is also equipped with temperature regulating devices and the annealing cycle is recorded on charts.

Foundry has Electric Ovens (Iron Age, June 17, 1926, vol. 117, pp. 1703–1707). An illustrated account of the equipment of the foundry of the Ross-Meehan Foundries at Chattanooga. Metal melting, mould and core drying and annealing are carried out in electric furnaces and ovens.

F. G. Steinebach, *Secures High Production with Conveyor System* (Foundry, Oct. 1, 1926, vol. 54, pp. 760–765). An illustrated account of the conveying system in operation at the Superior Foundry Co., Cleveland, Ohio.

E. H. Trick, *Erects Modern Casting Plant in Texas* (Foundry, Aug. 15, 1926, vol. 54, pp. 622–626). The equipment and practice of

the Alamo Ironworks, San Antonio, Texas, for the manufacture of grey iron castings is described and illustrated.

Consummated Deflation shown in Foundry Count (Foundry, Aug. 15, 1926, vol. 54, pp. 627–632). Statistical information relating to the number of foundries in operation in the different States of the United States and Canada.

Foundry Costs.—R. Dureuil, *A French Conception of Foundry Costing* (Paper read before the Association Technique de Fonderie: Foundry Trade Journal, 1926, vol. 33; May 30, pp. 358–359; May 27, pp. 376–378).

T. Smith, *What Individual Castings Cost* (Iron Age, Sept. 16, 1926, vol. 118, pp. 762–763). The author illustrates methods of analysing costs of materials and of moulding.

L. Schmid, *Account-Keeping in Foundry Undertakings* (Die Giesserei, 1926, vol. 13; Oct. 9, pp. 765–774; Oct. 16, 785–793).

J. H. Hopp, *Reducing the Cost of Cleaning Ferrous Castings* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 48–59). The author makes a number of suggestions for reducing the time required to clean castings. The first factor tending to reduce cleaning costs is not that of cleaning-room equipment or methods, but comes directly under the general heading of equipment, moulding, and core making.

M. E. Nicholls, *Foundry Management, Organisation, and Costing* (Foundry Trade Journal, 1926, vol. 33, May 27, p. 380; vol. 34, Sept. 9, p. 220).

Training of Foundrymen.—W. H. Dosey, *Training for Foundry Executives* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926).

R. E. Wendt, *Foundry Instruction at Purdue University* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926).

H. L. Campbell, *A Course on Cast Metal* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926).

H. O. Haughton, *Foundry Instruction at the University of Illinois* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926).

The foregoing four papers discuss foundry instruction at the Carnegie Institute of Technology, Purdue University, University of Michigan, and University of Illinois. An outline of the courses, together with details of instruction, are given.

Course in Foundry Studies (Iron Age, July 29, 1926, vol. 118, pp. 279–281). An outline is given of the methods of training foundry apprentices at the Indianapolis Arsenal Technical High School, including the six-weeks' course for general students.

H. Resow, *Application of Timing in Steel Foundry Operations* Stahl und Eisen, May 27, 1926, vol. 46, pp. 706–714). The intro-

duction of the system of timing all the operations involved in producing steel castings is shown to be practicable in a steel foundry, provided the right kind of men are selected for recording the times. Such records have proved to be of great utility in calculating piece rates and in framing estimates.

The Time Factor in Ironworks (Stahl und Eisen, June 24, 1926, vol. 46, pp. 840–844). The article is an abstract of a lengthy report on the possibility of increasing the efficiency and economy of ironworks and foundries by a system of careful timing of operations, and by studying how to eliminate all superfluous movements on the part of the workers.

PRODUCTION OF STEEL.

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I.—*PROCESSES OF STEEL PRODUCTION.*

Crucible Steel.—H. R. Simonds, *Auto Parts are Cast from Crucible Steel* (Iron Trade Review, Sept. 30, 1926, vol. 79, pp. 850–851, 897; Foundry, Sept. 1, 1926, vol. 54, pp. 674–675, 693). An illustrated account of crucible steel making practice at the plant of the Nutmeg Crucible Steel Co., Stoney Creek, Connecticut, for the production of automobile castings. Two oil-fired pits, each holding eight crucibles of 115 lbs. capacity, are in operation.

J. A. Coyle, *Making High-Grade Steel* (Iron Trade Review, May 6, 1926, vol. 78, pp. 1177–1179). The author classifies the various types of steel used in the manufacture of tools, and illustrates a number of sections and shapes for dies, tools, files, drills, axes, &c.

H. J. Stoewer, *Theoretical and Practical Questions in the Manufacture of Tool Steel* (Maschinenbau, 1926, Supplement, Zerspanung, pp. 50–54). The choice of high-speed steel to meet the particular workshop conditions, and the economy of the use of welded tools are considered.

A New Incandescent High-Temperature Melting Furnace (Metal Industry, July 16, 1926, vol. 29, pp. 60, 61). The furnace operates on town gas at ordinary main pressure and low pressure air-blast (6-inch to 10-inch water-gauge) preheated in a recuperative down-draught tower placed at the back of the melting chamber. Carborundum is used for the inner walls of the regenerator, while the outside is of low heat conductivity firebricks. Temperatures up to 1700° C. can be rapidly and economically attained.

Bessemer and Open-Hearth Processes.—H. Bansen, *Influence of the Materials and Length of Charging Period on the Heat Balance and Temperature Range of a Basic Bessemer Charge* (Stahl und Eisen, Sept. 23, 1926, vol. 46, pp. 1277–1283). The thermal conditions of a basic Bessemer charge have been studied. The various materials charged have been evaluated according to their heat generating capacity, and

the influence of these on the development of the heat required for the refining operation is considered. A large number of data are presented in tabular form, to enable the steel melter to calculate the thermal conditions of any individual case. The question of the quality and quantity of the limestone used is of particular importance. Each 1 per cent. of impurities in the limestone is responsible for a reduction of the bath temperature by 8·12° C. Each 1 per cent. of carbon dioxide lowers it by 10·44°, and each 1 per cent. of water by 33·7°. In view of the strong cooling effect of lime the additions of it should be carefully measured. A source from which some heat may be restored to the bath is by the combustion of the carbon monoxide, in which form a large proportion of the burnt carbon residues is present above the bath surface. At Krupp's Rheinhausen Works the combustion of this gas on top of the bath has been effected by means of lowering a tuyere through the opening of the converter through which an air-blast is blown.

H. M. Boylston, *Fundamental Reactions Involved in the Making of Iron and Steel* (Fuels and Furnaces, Mar. 1926, vol. 4, pp. 289–295). A discussion of the chemical properties of iron and the chemical and physical principles involved in the manufacture of iron and steel. Definitions of the terms cast iron, pig iron, wrought iron, ingot iron, and steel are included.

L. Dlougatch, *A Correction concerning the Use of Physically Hot Pig-Iron in Converters* (Revue de Métallurgie, Mémoires, July 1926, vol. 23, pp. 390, 391). In a previous article (see Journal of the Iron and Steel Institute, 1926, No I. p. 546) Lepetre appeared to think that Holz was the first to introduce an open-hearth furnace between the pig-mixer and the converter, and that Springorum was the first to appreciate the necessity for making the pig-iron sufficiently hot before introducing it into the basic converter. The present author points out that the furnace used was not an open-hearth, but simply a furnace fitted with Siemens regenerators; also that the credit for superheating the pig-iron should be given to Tschernoff and Potenoff, and that Pavloff first pointed out the need for sufficient heat in the metal before basic conversion. The history of the development of these two ideas, which were introduced to make possible the conversion of low-silicon or low-phosphorus irons, is sketched.

F. Bernhardt, *A Comparison of the Basic Open-Hearth and the Basic Bessemer Processes* (Revue Universelle des Mines, Aug. 15, 1926, vol. 11, pp. 195–199). A résumé in French of an article appearing in Stahl und Eisen (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 571).

S. J. Cort, *Comparison of Open-Hearth Furnaces of Various Sizes* (Paper read before the American Iron and Steel Institute, May 21, 1926). The author deals with the subject more from the economic than the technical point of view. The factors that directly affect open-hearth production and costs, irrespective of the size of the furnace, are considered in the following order: physical layout, materials used, and grade of

steel manufactured. Two other points are also discussed briefly—namely, the relative cost of construction of the various sizes of furnaces and their adaptability to the different percentages of pig-iron and scrap that may be necessary for a plant to use. The author concludes that from the standpoint of capital invested the 100-ton stationary furnace is the most economical to build and gives the most satisfactory results when using 40 to 65 per cent. hot metal. The large tilting furnace, while having the higher initial cost, can more than offset this by the saving in operating costs, providing it is possible to utilise it either on a high steel scrap charge varying from 60 to 80 per cent., or using it for the duplex process. The large furnace, while it is able to produce at a lower cost, will not be able entirely to displace the 60 to 70 ton furnaces in shops making a wide range of alloy steels where only small tonnages of a given composition are required.

M. Bouffart, *Management and Control of an Open-Hearth Furnace* (Revue de Métallurgie, Mémoires, July 1926, vol. 23, pp. 381–389). The author describes the equipment necessary to attain automatically and with precision scientific management and control of an open-hearth furnace. Among the apparatus which he advocates are automatic gas analysers to determine the composition of the gases supplied by the producers and of the waste gases, meters for measuring the amount of gas and secondary air supplied, pyrometers, and pressure recorders to indicate the pressures in the various flues in which the gases and air circulate.

E. Herzog, *Remelting Pig-Iron in the Open-Hearth Process* (Foundry Trade Journal, June 24, 1926, vol. 33, pp. 500–501). An English translation of the report by Herzog on the remelting of pig-iron in cupolas the original of which appeared in Stahl und Eisen, Mar. 18, 1926, vol. 46, pp. 357–358 (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 574).

R. S. Kerns, *Simplify Ferro-Alloy Additions* (Foundry, July 1, 1926, vol. 54, pp. 514–516). A chart is presented which gives the required weight of ferro-alloy to be added to a heat of iron and steel, when the weight of the charge, the percentage of alloying element in the ferro, and the number of points the alloy in the product is to be raised, are known.

C. H. Herty, jun., and J. M. Gaines, jun., *Desulphurising Action of Manganese in Iron* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The authors have studied the extent of, and the factors controlling, the elimination of sulphur in the ladle. High-sulphur low-silicon iron is economical in both the blast-furnace and the open-hearth, provided the sulphur can be eliminated to the desired point in the final steel. High-manganese iron serves to bring about this elimination before the iron is charged into the open-hearth. In ladles of molten pig-iron the equilibrium between manganese and sulphur at 2400° F. is expressed by the relation :

$$(\text{per cent. Mn})\ (\text{per cent. S}) = 0 \cdot 070,$$

above which the elimination of sulphur takes place, and below which

elimination is not effected. If blast-furnace slag is present in the ladle sulphur may be reduced from the slag into the metal. If the manganese sulphide eliminated from the iron is poured into the open-hearth the advantage of desulphurisation by high manganese is lost. The desulphurising action of the manganese takes place in the metal and is independent of interaction between slag and metal. The presence of slag on the metal tends to offset the effect of manganese elimination. It is this fact which distinguishes desulphurisation in the ladle from desulphurisation in the mixer.

G. F. Comstock, *The Treatment of Steel with Ferro-Carbon-Titanium* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 405).

P. H. Schaeffer, *The Basic Open-Hearth Charge* (Mining and Metallurgy, Oct. 1926, pp. 433–435). An outline is given of the nature of the components making up the charge for basic open-hearth practice. Charging practice is also briefly discussed.

A. McCance, *Basic Open-Hearth Reactions* (Journal of the West of Scotland Iron and Steel Institute, Session 1925–26, Part 3, vol. 33, pp. 45–52). The author applies the laws of physical chemistry to those reactions relating to the deoxidation of steel in the basic open-hearth process. The reduction of manganese from a basic slag, the influence of carbon on the equilibrium, and the removal of phosphorus, are discussed.

A. N. Diehl, *Data Relating to Basic Open-Hearth Steel Practice* (Paper read before the American Iron and Steel Institute, May 21, 1926). The results are given of a detailed investigation on basic open-hearth practice as carried out at the Duquesne Works of the Carnegie Steel Company, using furnaces of 50 to 75 tons capacity. The purpose of the paper is to submit the data and information as outlined rather than to express definite conclusions, which necessarily would not be applicable when local conditions and materials were taken into consideration. The first part of the paper discusses in detail the construction of the furnaces, types of heats investigated, and the methods of testing the material. The results of the investigation are presented in nineteen tables, with accompanying charts. A history sheet gives the weight, time, and analyses of all additions, the analyses of the slag and metal in the furnace, and the weight, time, temperature, and analyses of slag leaving the furnace. The amounts of coal gasified and producer or natural gas entering the furnace are shown, together with the amount of air entering and the waste gas leaving the furnace. Graphs show the analyses of the steel and slag throughout the heat, the temperature of the bath, and the time and amount of additions. From these curves the rapidity of oxidation for the various elements may be observed, and the action of various additions or changes in furnace operation studied. There is also a discussion on the action of metalloids in the furnace and the addition of alloys. One section of the paper is devoted to electric furnace practice at the Duquesne Works. The duplex process is used,

employing an open-hearth furnace in conjunction with a 20-ton Héroult furnace. Particulars are also included of a method for obtaining the total sulphur content of fuel gas, and a method for the rapid calculation of the amount of ore and limestone which should be charged for a heat of open-hearth steel.

J. H. Whiteley, *The Function of Ferric Oxide in the Acid and Basic Open-Hearth Processes* (Revue de l'Industrie Minérale, Aug. 15, 1926, No. 136, pp. 369–373). The article is a full translation into French by G. Husson of the author's paper presented at the joint meeting of the Iron and Steel Institute and the Faraday Society, held on June 8, 1925.

R. L. Cain, *Manufacture of Forging Steel by the Basic Open-Hearth Process* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). The following controlling factors and the precautions to be taken in the manufacture of forging steel are discussed: (1) Character of the charge, (2) working of the heat, (3) tapping and ladle additions, (4) teeming, and (5) metallurgy. Illustrations are included showing the analysis of an ingot poured in an inverted mould, and one poured in a Gathmann mould with a hot-top.

H. D. Hibbard, *Rimmed Steel and How it is Made* (Iron Age, 1926, vol. 117, June 24, pp. 1778–1780; vol. 118, July 15, pp. 142–143; July 22, pp. 214–215). A detailed discussion of the manufacture, properties, and uses of rimmed steel. The distinctive feature of rimming steel is the escape of gases in profusion from the molten steel in the mould, which dislodges gas bubbles formed against the frozen shell of the ingot, and also favours the elimination of non-metallic impurities. The gases of effervescence are essentially the same as those which cause the bath to boil in the furnace, the chief constituent being carbonic oxide. The particular physical features of an ingot of good rimmed steel are a solid outer skin and certain gas-holes. These gas-holes occur in three distinctly different ways, and are therefore manifestly caused by three different gases. According to their position in the ingot they are known as skinholes (thought to contain hydrogen), intermediate holes (thought to contain carbonic acid), and central holes (thought to contain nitrogen or ammonia, or both). For obtaining the desired rate of effervescence in the mould it is necessary to have an adequate boil in the furnace, particularly at the end. The amount of stirring given to the bath should be limited to that required to make it fairly uniform in composition before sampling. No additions should be made at the end of the heat or in the ladle unless the boil is too vigorous. If any addition is made to the bath, as for raising the carbon content, tapping should not take place until the bath has resumed its normal activity. Residual manganese should not be above 0·15 per cent. for bottom casting, or above 0·10 per cent. for top casting. The correct casting temperature is an important point to be observed.

The character of the slags, the appearance of a scum on top of the ingot, segregation and chemical structure of the ingot, are also discussed.

E. de Loisy, *On the Speed of Elimination of Carbon in the Open-Hearth Furnace* (Revue de Métallurgie, Mémoires, July 1926, vol. 23, pp. 369–380). The author has investigated the mathematics of the chemical reactions in the open-hearth furnace; he finds that, under normal conditions, where the bath of metal is covered with sufficient slag with an excess of iron oxide, the speed of decarburisation is at every instant proportional to the amount of carbon remaining in the bath. This can be expressed mathematically by an equation resembling that representing the kinetics of monomolecular reactions, but this resemblance is purely accidental, as the equation does not represent the velocity of the reaction $FeO + C = CO + Fe$, which proceeds practically instantaneously at 1500° C., but the law of diffusion of carbon through the metallic bath up to the slag. This law shows that the period of the operation is proportional to the square of the depth of the bath. It can be applied to all cases of refining reactions between a metallic bath and the overlying substance, whether liquid or gaseous.

B. M. Larsen and J. W. Campbell, *Optical Temperature Measurements in Open-Hearth Furnace* (Paper read before the American Institute of Mining and Metallurgy, Oct. 1926). This paper gives the results of experiments made: (1) To determine the accuracy of flame-off optical temperatures on wall and roof surfaces by comparison with some other method of measurement (with temperatures obtained by extrapolation of gradient curves); (2) to measure flame-on and flame-off temperatures in order to determine the effect of flame reduction under different conditions; and (3) to measure temperatures of roof, wall, and slag surfaces so as to determine the distribution of temperatures in different parts of the melting chamber during steel-making. After a review of previous investigations and possible errors in optical measurements, the apparatus and method used in the present investigation are described and the results tabulated, discussed, and illustrated graphically. The conclusions are that all surfaces are at practically the same temperature during steel-making, due to the speed of radiation exchange. As the bath comes up in temperature, the differences in heat between the hearth and steel, which are much cooler in the early melting, and the side walls, port, and roof decreases. Cooling during repair between heats is rapid but uniform. The furnace chamber approaches "black-body" conditions, especially near the end of the heat, making flame-off optical temperatures very nearly accurate. Surface temperatures must be read at once after flame shut-off. Flame reflection always raises apparent temperatures of wall and slag surfaces. The range of safe steel-making temperatures is given for silica arches or walls, and finishing temperatures for slow-working and fast-working furnaces. Local overheating, especially when approaching the "danger zone" of temperatures, may be caused by an impinging stream of hot gases or flame.

P. Goerens, *Steels of Different Qualities and their Relation to the Methods of Production* (Zeitschrift des Vereines Deutscher Ingenieure,

1926, vol. 70; Aug. 14, pp. 1094–1099; Aug. 21, pp. 1129–1136; Sept. 4, pp. 1194–1198). To meet various conditions and applications in industry steels of various qualities have been developed. In the production of these it is impossible, for economic reasons, to use only the purest raw materials and work on a small scale; the producer must do the best he can with raw materials which are abundant, though often of poor quality, and must aim at perfecting his processes of production and at controlling the many variables to be taken account of in the manufacture of his steel products, so as to obtain not only a trustworthy material for the purpose in view, but the ability to produce it over and over again of unvarying quality.

E. Lubojatzky, *Fundamental Factors in the Scientific Production of Particular Kinds of Steel* (Montanistische Rundschau, 1926, vol. 10; May 16, pp. 321–326; June 1, pp. 353–356; June 16, pp. 382–384). A study of the physical chemistry of steel-making.

M. Hamasumi, *On the Macroscopic Determination of Carbon Content of Samples in Open-Hearth Process* (Kinzoku no Kenku, 1926, No. 1, pp. 54–64).

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment. Part VIII.* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 285–298). The paper covers the manufacture, properties, and uses of plain carbon steels, other than tool steels, from the standpoint of the consumer. The manufacturing processes are briefly touched upon, and the effect of different carbon contents upon the properties of the steels is described. Examples are given of the uses of the different grades and classes of steel.

W. C. Hamilton, *Open-Hearth Slags* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926: Foundry Trade Journal, Oct. 14, 1926, vol. 34, pp. 331–333). The author discusses the function, composition, and control of acid and basic slags in the open-hearth process.

A. Reynaud, *A Large American Steelworks. A Description of the Indiana Harbour Works of the Inland Steel Co.* (Revue de Métallurgie, Mémoires, 1926, vol. 23; May, pp. 277–291; June, pp. 331–341). A very detailed account, accompanied by illustrations of the plant; the history of the works is also briefly related.

L. C. Edgar, *Steel-Plant Operating Costs from an Engineering Point of View* (Proceedings of the Engineers' Society of Western Pennsylvania, Apr. 1926, vol. 42, pp. 165–180). The primary object of this paper is to cover in a general way a few of the fundamental principles governing engineering in its relation to the production of iron and steel of good quality at a low cost.

Electric Steel Furnace Practice.—L. Lyche and H. Neuhauss, *Heat Balance of a High Efficiency Electric Furnace of the Héroult-Lindenberg Type* (Stahl und Eisen, June 10, 1926, vol. 46, pp. 780–782; Steelworks Committee Report, No. 101, 1925). The authors present the working

results and a heat balance of a 6-ton Héroult furnace equipped with a 2000 k.v.a. transformer at the Glockenstahlwerke, formerly R. Lindenberg, at Remscheid. The furnace formerly worked with a transformer of 1175 k.v.a., and the results with the new transformers are compared with those previously obtained :

	1175 k.v.a. Transformer.	2000 k.v.a. Transformer.
Melting-down time, per ton	49 min.	28 min.
Current consumption per ton for melting .	540 kw.-hr.	480 kw.-hr.
Electrode consumption per ton of charge .	13·5 kg.	16·17 kg.
Life of roof	50–60 heats	50–60 heats

The melting current was 173 volts pressure in both cases, and the figures represent the average of 93 heats in the case of the 1175 k.v.a. transformer and of 101 heats in the case of the new one. In the trials to determine the efficiency the charge consisted of 7500 kilogrammes of scrap with 80 kilogrammes of burnt lime ; 150 kilogrammes of pig and 60 kilogrammes of 44 per cent. ferro-silicon were added. The melting-down time was 3 hours 22 minutes, with a current consumption of 3350 kilowatt-hours, and the refining period was 3 hours 28 minutes, the consumption being 2200 kilowatt hours. The total efficiency of the furnace is calculated at 45·7 per cent., the efficiency during melting down being 70 per cent., and for the refining operations 22·5 per cent. Tables showing the heat input, heat output, and electric losses are given.

F. Sommer, *The Proportions of Transformers for Electric Arc Steel Furnaces* (Stahl und Eisen, July 8, 1926, vol. 46, pp. 909–913). In reply to a circular inquiry a number of German electric steelworks submitted data concerning transformer efficiency, and from these diagrams are plotted showing the transformer output in k.v.a. for charges of 2 tons up to 10 tons during the melting period and the refining operations in electric arc furnaces.

B. Egeberg, *On Electric Steel Melting* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 395–408). The author discusses the problems encountered in the manufacture of high-grade steels, especially tool steel, in the electric furnace. The advantage and economic value of the electric furnace, for melting and oxidising, desulphurising, and deoxidising, are dealt with. A comparison is drawn between the acid open-hearth, the crucible furnace, and the basic electric furnace as regards deoxidation. The nitrogen content of basic electric steel may vary greatly, but the author, after experiments covering a period of years, concludes that there has never been found any relation between the nitrogen content and the quality of the tools produced.

J. R. Jackson, *Electric Furnace Makes Quality Steel* (Iron Trade

Review, Sept. 9, 1926, vol. 79, pp. 644–645). The development of various types of electric furnaces for steel-making is briefly discussed, and short notes are given of the types now in use.

F. W. Manker, *Furnaces Important in Production of Roller Bearings* (Iron Trade Review, Sept. 2, 1926, vol. 79, pp. 563–565). An illustrated description of the manufacture of roller bearings at the plant of the Timken Roller Bearing Co., Canton, Ohio. Steel is produced in Héroult furnaces, and the ingots are reduced in a 35-inch blooming-mill and a 22-inch bar-mill. A piercing mill is employed for the production of the tubes. Details are included of the reheating furnaces in operation.

E. Blau, *The Installation, Operating Characteristics, and Economy of Nathusius Furnaces* (Chemiker-Zeitung, 1926, vol. 50, pp. 6–7, 26–27). A detailed description of the Nathusius electric furnace and its auxiliary equipment.

A 100,000-*Ampere Electric Furnace* (Electrical Review, Oct. 8, 1926, vol. 98, pp. 597–598). It has been found that larger electric furnaces are more efficient than smaller ones, and that a reduction of the number of electrodes is desirable. The article describes an electric furnace erected in France which has a single electrode 7 feet 6 inches in diameter and 4 feet high. The hearth is circular, but the plan of the exterior is a star-shaped polygon; the furnace body is built of ferro-concrete, and is air- and liquid-tight. The power factor of the furnace is 0·949, but this is lowered at the primary of the four transformers to 0·930, owing chiefly to leakage and magnetising current.

J. H. Hruska, *Chromium-Nickel Electric Ingots* (Revue Universelle des Mines, June 15, 1926, vol. 10, pp. 288–296). A French translation and résumé of an article appearing in Iron Age. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 582.)

E. de Loisy, *The Theory of Electric Arc Furnaces in the Light of Recent Work* (Revue de Métallurgie, Mémoires, May 1926, vol. 23, pp. 253–268). The paper deals with the electrical side of the furnaces.

N. R. Stansel, *The Temperature Control of the Metallic Resistor Type Electric Furnace* (Fuels and Furnaces, Feb. 1926, vol. 4, pp. 215–219). A discussion of temperature distribution, rate of heating, constancy of temperature, and rate of cooling in the metallic resistor type of electric furnace for heat treatment.

N. R. Stansel, *Notes on the Design of Metallic Resistor Type Electric Furnace* (Fuels and Furnaces, Mar. 1926, vol. 4, pp. 347–349).

J. D. Keller, *Auxiliary Equipment for Electric Furnaces* (Fuels and Furnaces, 1926, vol. 4; May, pp. 541–548; June, pp. 661–672; July, pp. 789–794, 832; Aug., pp. 895–900, 930). The subject is dealt with under the following headings: pyrometers and temperature recorders; automatic temperature regulators; control panels, meters, and transformers; and equipment for melting furnaces of the resistance and arc types.

R. Pitaval, *Manufacture of Electric Steel in France during the Past Twenty-Five Years* (Journal du four électrique, 1926, vol. 35, pp. 81–83).

II.—*CASTING AND TREATMENT OF INGOTS.*

F. Leitner, *Influence of Thickness of Ingot Mould Wall on the Ingot* (Stahl und Eisen, May 13, 1926, vol. 26, pp. 629–631). Experiments were made in the steelworks of Böhler Brothers, Austria, to determine the effect of walls of different thicknesses in ingot moulds. The class of steel studied was chrome-nickel steel: and three sizes of ingot were examined—namely, 5½ inches and 9 inches in diameter, and 10 inches square. The teeming temperature was about 1650° C. For the 5½ inch round ingots the walls of the moulds varied from 55 to 25 millimetres thick; for the 9-inch ingots the walls of the moulds ranged from 65 to 30 millimetres, and for the 10-inch square ingots they varied from 75 to 35 millimetres. The influence of the different thicknesses was the same in all cases. The medium thicknesses gave the best results as regards the formation of the crystallites, and the time of solidification was about the same for all thicknesses. Etched sections of the ingots are shown.

F. Leitner, *The Influence of Mould Wall Thickness* (Forging, Stamping, Heat Treating, July 1926, vol. 12, pp. 245–247). A translation of the above article.

The Thickness of Ingot Moulds (Metallurgist, June 25, 1926, p. 92). A brief review of present-day opinions on the effects of the thickness of ingot moulds, followed by a short summary of the results of Leitner.

Sir Robert Hadfield, *Heterogeneity of Steel Ingots and Sound Steel* (Metallurgist, Aug. 27, 1926, pp. 119–124). Strong emphasis is laid on the necessity for the making of sound steel. By "sound steel" is meant steel which not only does not rise in the mould, but shows distinct settling or piping. The results obtained by casting sound and unsound steel into small green sand, dry sand, and cast-iron moulds are described, and tests for soundness based on this behaviour are suggested.

J. H. Hruska, *Chemical Analyses of Large Ingots* (Iron Age, Apr. 15, 1926, vol. 117, pp. 1049–1050). The author emphasises the importance of the relationship between chemical analysis and soundness in the classification of certain grades of steel. A number of analyses of steel ingots produced by different processes are tabulated.

P. Eyermann, *A New Lathe for Turning Ingots of High-Quality Steel* (Stahl und Eisen, Aug. 12, 1926, vol. 46, pp. 1083–1084). For the manufacture of high-quality steel, round ingots have largely come into use, on account of the greater ease with which the surface can be cleaned up. It is recognised, however, that ingots of square section are not subject to such defects arising from the cooling conditions as are found in round ingots. The author has devised a special type of lathe for the rapid machining of square ingots of nickel-chromium steel and other kinds of alloy steels.

FORGING AND ROLLING-MILL PRACTICE.

Reheating Furnaces.—E. W. Trexler, *Continuous Bloom and Billet Heating Furnaces* (Paper read before the Association of Iron and Steel Electrical Engineers, June 1926). Proper furnace proportions as to size of combustion chamber, height and type of roof, proper size of gas passages, type and location of burners, length of flame, type of fuel, and means for the removal of cinder, all play a prominent part in maintenance costs of heating furnaces. The life of refractories in the older types of furnaces was surprisingly short, especially with direct coal firing, therefore water-cooling has been employed to reduce replacements. In the new types of furnaces, water-cooling of the roofs has been eliminated, and the flat suspended roof is giving satisfactory service in continuous bloom- and billet-heating furnaces. Air-cooling is considered to be better than water-cooling for the hearths. Water-cooled skid pipes are stated to be detrimental to efficiency owing to the black spots left on the heated billet. Elimination of water-cooling in heating furnaces is important from the efficiency standpoint, as the heat absorbed by the water is from 2 to 5 per cent. of the total heat supplied by the fuel.

M. Laffargue, *A Study of Continuous Reheating Furnaces* (Chaleur et Industrie, May 1926, vol. 7, pp. 264–268). The author discusses all the factors, such as fuel, type of flame, shape and size of furnace, regeneration, &c., which come into play in the heating of iron in a continuous reheating furnace, and shows how the best values for furnace dimensions and other details may be calculated according to the particular conditions of any individual case.

C. Gerrard, *A Direct Method of Calculating the Size of Continuous Reheating Furnaces* (Iron and Coal Trades Review, July 2, 1926, vol. 113, p. 3).

Regenerator Pusher Type Furnace for Heating Blooms (Fuels and Furnaces, July 1926, vol. 4, p. 807). Particulars are given of a regenerative continuous furnace of the pusher type recently built in Germany for heating blooms $6\frac{1}{4} \times 6\frac{1}{4} \times 86$ inches. The furnace has a capacity of 39 to 48 tons per hour when the blooms are charged cold and heated to a temperature of 2200° to 2300° F. The furnace is equipped with regenerators for both gas and air, and the flue gases are utilised for raising steam. The heat balance of the furnace is as follows :

	Per Cent.
Heat imparted to blooms	52·9
Heat to cooling water	10·1
Heat in slag	0·9
Heat in products of combustion	26·0
Heat losses by radiation and convection	10·1
	100·0

W. H. Fitch, *Recuperator Principle Applied to Reversing Reheating Furnace* (Fuels and Furnaces, Apr. 1926, vol. 4, pp. 457–458). The author describes a method in which recuperators may be applied to reversing flame furnaces.

W. H. Fitch, *Application of Recuperators to Sheet and Pair Furnaces* (Fuels and Furnaces, June 1926, vol. 4, pp. 723–724). Brief particulars are given of the arrangement of heating chambers and recuperators of an underfired semi-muffle furnace.

C. Longenecker, *Industrial Furnaces* (Iron Trade Review, 1926, vol. 79; Sept. 2, pp. 568–570; Sept. 16, pp. 721–723; Sept. 30, pp. 843–845). A series of articles on the design, construction, and function of melting, reheating, and heat treating furnaces.

C. H. Lawrence, *Heating Furnace Fired Mechanically* (Iron Trade Review, Sept. 16, 1926, vol. 79, pp. 720, 723). Particulars are given of the application of mechanical stoking to a billet-heating furnace. The furnace is 30 feet in length and has an output of 6½ tons per hour. At this rate of production 260 lbs. of coal are burned per ton of steel heated, or 27 lbs. per square foot of grate area, with forced draft at a pressure corresponding to 0·45 inch of water under the fire. A temperature of 3000° F. is maintained over the fuel bed and 2800° F. over the hearth. The billets leave the furnace at 2500° F. and the gases at 1800° F.

Forging, Pressing, Stamping, and Drawing.—E. G. A. Walker, *Notes on Forging Hammers* (Paper read before the Birmingham Association of Mechanical Engineers: Drop-Forger, May 1926, vol. 6, pp. 16–43). The author deals with the design and operation of steam or compressed air double-acting hammers, and steam drop and friction lift hammers of approximately 5 tons nominal capacity.

30-Cwt. Pneumatic Hammer (Machinery, June 24, 1926, vol. 28, p. 341). An illustrated description of a new hammer built by B. & S. Massey, Ltd. Light or heavy automatic blows at the rate of 75 per minute, and single blows of any desired force and length of stroke, can be given by a movement of the single control lever.

C. D. Harmon, *Progress in Machine Forging* (Paper read before the Production Standards Division of the American Plan Association, Cleveland, Mar. 1, 1926: Iron Trade Review, Sept. 2, 1926, vol. 79, p. 575). A comparison is made of the relative merits of machine-forging and drop-forging operations, and the action of steel when upset in a modern forging machine is explained. Because seams or cracks sometimes develop around the outer edge of a forging, there is a belief in some quarters that the outer portion of an upset is in tension. This, however, is not the case, as the entire upset is in compression—although it is true that this compression will open up any seams that may exist in the original bar.

W. R. Ward, *Multiple Breaking* (Transactions of the American Society for Steel Treating, July 1926, vol. 10, pp. 119–123). A method is

described for the rapid breaking of bars into short lengths for forging. The bars are notched by means of an oxy-acetylene torch and are broken in a hydraulic press. A number of alternate plus and minus bending moments are applied simultaneously, and the pressure of the fulcrum causes fracture of the bar.

R. E. Kerslake, *Forgeability of Steel Determined by the Brinell Machine* (Transactions of the American Society for Steel Treating, May 1926, vol. 9, pp. 773–776). The author describes a test for determining the suitability of a steel for cold or hot forging or upsetting. A Brinell machine is used, in which the 10-millimetre ball is replaced by a hardened steel cone. No specific load can be designated as the proper load for all types of tests. In making the test the operator observes the manner in which the specimen responds to the wedging action of the cone, and the amount of upsetting or distortion is evaluated in relation to the observed requirements in actual manufacturing operations.

O. W. Ellis, *Some Factors in Forging Steel* (Forging, Stamping, Heat Treating, May 1926, vol. 12, pp. 158–163). The more important factors affecting the forging of steel are four in number; two, due to the machine itself, are the energy of the blow and the velocity of the blow; the other two, due to the material being forged, are the volume of metal and its carbon content. The energy of the blow is not usually specified in forging practice, but is easily calculated, being the product of the sum of the weights of the moving parts into the distance dropped. Curves are reproduced showing the relationship between the energy of the blow and the percentage reduction in height of ½ inch normal samples. It is found that in steel at high temperatures the energy required to deform it varies within limits with the velocity of the blow; a distinction must be drawn between dynamic and static forces, because it has been shown that in static deformation the energy absorbed is less than would be expected from a consideration of dynamic test results. With regard to the volume of metal being forged, Tresca's law is very important; this says that the energy required to produce analogous changes of shape in geometrically similar bodies in a similar physical state varies as the volumes or weights of the bodies. If the carbon content of the steel exceeds about 0·45 per cent., its malleability, whatever its carbon content, is roughly the same at all temperatures above about 1000° C.; below 0·45 per cent. carbon the malleability increases fairly rapidly. Above about 1000° C. the relation between malleability and temperature is linear for all carbon contents. Four examples are calculated at the end of the article to show how the relationships given may be utilised in practice.

H. Bruns, *Consumption of Energy in Forging* (Stahl und Eisen, Aug. 12, 1926, vol. 46, pp. 1087–1090). The article is a study of the relative economy of steam-hammers and pneumatic hammers. A new low-pressure hammer driven by air at 2 to 3 atmospheres has been brought out, which with half the power consumption performs the same work

as a high-pressure pneumatic hammer using pressures of 6 to 8 atmospheres.

Kaessberg, Lehmann, and Oeser, *Ascertainment of the Working Time of Forgings* (Maschinenbau, Feb. 4, 1926, vol. 5, pp. 119–122). The authors have developed a furnace chart, which is described, for the ascertainment of the working time of forgings.

J. C. Kielman, *Forging by the Upset Process* (Transactions of the American Society for Steel Treating, Oct. 1926, vol. 10, pp. 599–614). The paper is concerned principally with the forgings used in the manufacture of ball-bearings. The steel and its peculiarities, as well as the method of forging, are discussed. A portion of the paper is devoted to an explanation of the upsetting process, and its application to the manufacture of ball-bearings. The advantages of this method are discussed and compared with other methods. The problems of forging dies and the steels used in their manufacture, and the importance of heat treatment are dealt with. The furnaces used for upset forging are also described.

E. Decherf, *Fins on Stampings and the Utility of Examinations of Macrostructure* (Revue Universelle des Mines, May 15, 1926, vol. 10, pp. 162–168). The author discusses the formation of fins on stampings. Sharp re-entrant angles and bends are apt to upset the flow of the metal constituting the fin, and this may in some cases affect the metal in the body of the piece. To determine this, and also to show generally that the metal has flowed in the most suitable manner so as to bring the fibres into correct relation with the stresses which the piece will have to withstand, the author makes use of macro-etchings.

O. B. Schultz, *Some Defects which have been Found in Large Carbon-Vanadium Forgings: Their Causes and Prevention* (Paper read before the American Society for Testing Materials, June 1926: Forging, Stamping, Heat Treating, July 1926, vol. 12, pp. 230–234). The author discusses defects due to manufacture, forging, and normalising. A steel which has been carefully manufactured in the open-hearth furnace, and correctly forged, presents no difficulties in the normalising process, and the forgings will meet easily the specifications of the railroads for this class of material.

Are Ghost Lines Injurious? (Metallurgist, Aug. 27, 1926, pp. 115–116). The occurence of ghosts in connecting-rod forgings is described and illustrated. The question whether the pieces ought to be rejected or passed is discussed, but no definite answer is given.

H. Brearley, *Ghost Lines in Steel* (Metallurgist, Aug. 27, 1926, pp. 116–119). The term "ghost" is often applied to any white line or band which becomes visible on machining; from the machinist's point of view this is, no doubt, satisfactory, but as these bands may have various properties and originate in many ways, the term should be qualified before starting to discuss "ghosts." The author restricts himself to white bands which rust readily and give a dark sulphur print —that is, to bands due to sulphide segregates. The mechanism of the

freezing of an ingot is described, and the mode of formation of the ghosts and the positions occupied by them are set forth. The time factor is suggested as a probable explanation of the non-appearance of ghosts in small ingots and their inevitable occurrence in larger ones. The method of procedure for taking test-pieces and testing them is briefly described, and the fact that the occurrence and location of ghosts in these test-pieces is purely a matter of chance is put forward as a reason for the revision of present-day methods of inspection; the author thinks that many large forgings are rejected which in reality are not at all inferior to others which are passed, simply because the test-pieces from the latter had the good fortune to have no ghosts in places where they would affect the test results.

J. H. Andrew, *The Formation of Ghost Lines* (Metallurgist, Aug. 27, 1926, pp. 124–125). An investigation now in hand suggests that the temperatures of the critical points of steels depend on the initial temperature to which they were heated. The manner in which the ferrite separates, which in turn controls the type of lamination or ghost that will be produced, is also dependent on the same cause. The special elements, such as nickel, chromium, manganese, &c., produce their beneficial results entirely by the influence they exert on the state of the carbon; it has been suggested that their effectiveness is proportional to their residual valencies. There appears to be some marked difference in constitution between mild and higher carbon steels; the line of demarcation seems to be in the neighbourhood of 0·45 per cent. carbon.

J. H. Whiteley, *Theories on Ghost Formation—A Criticism* (Metallurgist, Aug. 27, 1926, pp. 125–126). The author demonstrates the weak points in the two very widely differing explanations that have been advanced to explain the formation of ghosts, namely, that on the one hand heterogeneity (particularly as regards oxygen and phosphorus) is the cause, and that on the other hand crystallisation of ferrite on slag particles is the reason. An experiment is described which shows that the rate of cooling of the metal is an important factor. Mechanical tests show that there is no appreciable difference between banded and non-banded steels.

P. Oberhoffer, *Some Notes on Ghost Lines* (Metallurgist, Aug. 27, 1926, pp. 126–127). The author distinguishes between crystal segregation, blowhole segregation, and ingot segregation, and discusses the occurrence of each. He defines ghost lines as representing localised regions of concentration of impurities or inclusions in steel. Experiments carried out in his laboratory indicate that a more important influence must be ascribed to oxygen than has hitherto been done.

J. H. S. Dickenson, "*Ghosts*" (Metallurgist, Aug. 27, 1926, pp. 127–128). The author thinks that the question is not "Should ingots be free from ghosts?" but "Do ghosts injuriously affect the behaviour of forgings in practice?" In many cases ghost lines occur which have no ill effect on the metal, but in other cases they occur accompanied by "hair lines" or "hair cracks" which do very seriously affect the

mechanical tests taken across them. In his long experience the author has only once encountered a case where breakdown in service could fairly be associated with ghost lines. He is of opinion that the worst ghost line running longitudinally along a surface is not nearly such a potent source of danger, by providing the starting-point for a fatigue flaw, as the apparently insignificant circumferential scratches and tool marks often accepted by inspecting engineers without question.

J. H. G. Williams, *The Drop-Forging Process* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 409–435). The author describes in detail the drop-forging process from the inspection of the raw material to the finished product. In general, a direct oil-fired furnace is best for heating steel for this class of work. The construction and installation of this type of furnace is described. The effect of heat and mechanical work upon the structure of the steel is also considered. The size of the hammer to be used is largely determined by the area to be forged, and tables giving hammer ratings and hammer production are included. The paper concludes with an estimate of cost of producing certain types of drop-forgings.

G. A. Knechenmeister, *Safety Work in the Drop-Forge Shop* (Paper read before the American Drop-Forging Institute, May 1926 : Forging, Stamping, Heat Treating, Aug. 1926, vol. 12, pp. 284–288). The author quotes examples to show that the enforcement of safety rules and the complete guarding of equipment does result in a material reduction in the number of shop accidents. A "pulley catcher" for a board hammer is described.

F. W. Spencer, *Notes on American Drop-Forging Practice* (Drop-Forger, Nov. 1926, vol. 6, pp. 188–195).

M. W. Von Bernewitz, *The Steel Shovel—How it is Made* (Iron Age, July 29, 1926, vol. 118, pp. 273–274). Particulars are given of the methods of manufacturing steel shovels. A high-carbon steel with carbon ranging from 0·70 to 0·90 is used in the form of sheets.

F. W. Krebs, *The Cold-Drawing of Steel* (Paper read before the American Society of Mechanical Engineers, May 3–6, 1926 : Mechanical Engineering, May 1926, vol. 48, pp. 448–450). The paper describes the steps involved, and the equipment used by a mill specialising in alloy steels, in converting hot-rolled steel into cold-drawn bars. The factors governing the machineability, and the effects of cold-drawing on the physical properties of steel, are discussed. The results obtained with various grades of steel are tabulated.

R. C. Knoll, *The Production of Cold-Drawn Hot-Pressed Pipe Unions* (American Machinist, European Edition, May 15, 1926, vol. 64, pp. 565–568). The requirements for pipe unions, and the class of steel to be used, are discussed ; the dies for blanking and forging and the hot-press forging are described. The preservation and prolongation of the life of the dies is also briefly dealt with.

J. A. Coyle, *Making High-Grade Steel XIII.* (Iron Trade Review, July 15, 1926, vol. 79, pp. 137–139). A brief discussion of the production of cold die-drawn steel and its applications.

E. Sheldon, "*Blowing*" *a Shell of Heavy Sheet Steel* (American Machinist (European Edition), Sept. 11, 1926, vol. 65, pp. 233–234). The article describes the production of a machine part by a preliminary drawing process, using steel sheet $\frac{3}{16}$ inch thick, followed by a "blowing" process in which tallow is used as a medium to produce high pressure within the shell, so shaping it to the mould; owing to the shape of the shell, it is quite impossible to get a tool inside to do the work. This machine part was formerly made by casting and subsequent machining, and the new method is both quicker and more economical.

R. Becker, *The Mechanical Effects in Wire Drawing* (Stahl und Eisen, June 17, 1926, vol. 46, pp. 811–812; Zeitschrift für technische Physik, 1925, vol. 6, pp. 298–306). An investigation was made to establish the theoretical principles by which the power required to draw wires may be determined. The author starts from the law of energy according to which the minimum amount of work required to produce a certain amount of deformation is always the same, no matter in what manner the deformation takes place. The subject is treated mainly from a mathematical point of view.

Latrecal, *Steel Wire for Winding Ropes* (Génie Civil, July 31, 1926, vol. 89. pp. 97–99). The Comité Central des Houillères de France has collected information from a number of French and foreign experts with a view to establishing more precise conditions for the manufacture of steel wires for winding ropes. The wire, of open-hearth steel, should have a carbon content not lower than 0·60 and not above 0·80 per cent., and after two or three drawings it should receive a suitable heat treatment, and then be subjected to at least four further drawings in order to impart to it the correct molecular arrangement for the best degree of flexibility. The tests which wires and finished ropes should undergo are prescribed.

A. G. Warren, *Barbed Wire—Who Invented it?* (Iron Age, June 24, 1926, vol. 117, pp. 1769–1774). The author puts forward a few of the facts and circumstances relating to the introduction of barbed wire in the United States. It is shown that the basic ideas of barbed wire construction were embodied in patents filed in the years 1867 and 1868. Since that time more than 200 different varieties have been patented.

C. W. Lucas, *Selecting Proper Size Press for Blanking* (Paper read before the National Pressed Metal Society, Chicago, Ill., Feb. 1926: Forging, Stamping, Heat Treating, Aug. 1926, vol. 12, pp. 280–283). The author discusses the method of calculating the correct size of press for blanking, punching, drawing, &c., and compares various types of power presses.

Special Flanging Press for Bridge Flooring (Engineer, June 25, 1926, vol. 141, pp. 674–675). The press is capable of forming single and double-fluted troughing and other shapes from material up to 30 feet long by 6 feet wide. The material is heated in a furnace, coal-fired on the "Priest" patented saturated fan-blast system. The press is of the bottom cylinder type, and has a total power of 1000 tons. The press can be worked as one unit, or one half lengthwise can be isolated, and

the centre portion of the table throughout its length can be operated separately. In order to economise pressure water, four of the main side cylinders raise the table to the work, the remaining main cylinders being filled from an overhead tank previous to the admission of pressure water. This machine is also described under the title "1000-Ton Flanging Press" in Machinery, Aug. 12, 1926, vol. 28, p. 569.

Rolling-Mill Equipment.—*The Consett Iron Company's New Plate Mill* (Iron and Coal Trades Review, June 25, 1926, vol. 112, pp. 1000–1005; Electrical Review, June 18, 1926, vol. 98, pp. 902–905). A detailed illustrated description is given of the electrical equipment of the new plate mill of the Consett Iron Co. The new plant consists of a 40-inch two-high reversing slabbing mill, a 42-inch two-high reversing plate mill, a 32-inch three-high light plate mill, and a 30-inch chequer plate mill. For the supply of the necessary power a generating station has been put down equipped with two 3000-kilowatt three-phase turbo-alternators and a 1000-kilowatt direct-current geared turbo-generator, and in addition three 1500-kilowatt rotary converter sets have been installed for supplying direct current for auxiliary power.

F. Labaye, *Note on the Blooming-Mills of the John Cockerill Company* (Revue Universelle des Mines, Aug. 1, 1926, vol. 11, pp. 110–114). A description of the blooming-mills built by Messrs. Cockerill in their own works. They follow on the lines of American practice; the principal measurements are: diameter of rolls, 790 millimetres; length of table, 2032 millimetres; lift, 850 millimetres. The rolls are of forged steel. A throughput of 75 metric tons per hour is attained; the consumption of electric power in one of the tests described was 12·6 kilowatts per ton of ingot. The plant is fitted with steam-hydraulic shears.

Steel Strip Rolling at Sandviken (Engineer, Apr. 23, 1926, vol. 141, pp. 466–468, 470). An illustrated description of the works of the Sandvikens Jernwerks Aktiebolag, with particular reference to the production of hot- and cold-rolled strip for making band-saw blades.

A. L. Foell, *New Electric Blooming-Mill Drive* (Iron Age, Apr. 15, 1926, vol. 117, pp. 1051–1054). Particulars are given of the new electric equipment for driving the 36-inch blooming-mill at the plant of the Donner Steel Co., Inc., Buffalo. The new drive replaces a steam-engine, and the change-over was made in the quick time of $13\frac{1}{2}$ working days.

M. J. Conway, *Additions to Rolling-Mills at Steubenville Plant of the Wheeling Steel Corporation* (Paper read before the Association of Iron and Steel Electrical Engineers, June 1926). Particulars are given of new equipment at this plant, which consists of a 35-inch two-high blooming-mill and a 19-inch continuous bar-mill, with the necessary shears, delivery, and loading equipment. A new boiler plant, power plant, gas-producer plant, and two additional rows of soaking pits have also been installed.

Blooming-Mill of Massive Size (Iron Age, Aug. 5, 1926, vol. 118, pp. 348–350). The 54-inch two-high reversing blooming-mill recently

erected at the Homestead Works of the Carnegie Steel Co. is described and illustrated. The mill, which is considered the largest and heaviest yet built, has a total height of 38 feet. The housing is built up of six sections, and the weight of each roll is about 45 tons. The mill is equipped with a double motor-operated manipulator for handling 15-ton ingots.

J. D. Knox, *Merchant Bar-Mills now under Power* (Iron Trade Review, June 24, 1926, vol. 79, pp. 1617–1621). An illustrated account of the four new merchant mills recently put into operation at the Cambria Works of the Bethlehem Steel Corporation; they comprise 14-inch, 13-inch, 10-inch, and 9-inch mills. Each mill is housed in a separate building. Miscellaneous shapes are produced in the 9-inch mill. The roughing rolls consist of a train of four stands of 12-inch rolls arranged in pairs and tandem, driven by a 1000 horse-power motor. The finishing mill includes five stands of 9-inch rolls—two three-high and two two-high—driven by a 1000 horse-power motor, and one two-high stand driven by a 500 horse-power motor. Stock is either looped from one stand to another, or is run out on chutes, when it is to be fed into an adjacent stand of rolls. The 10-inch mill is designed to produce rounds, squares, flats, and concrete bars. The roughing train is continuous and includes four stands of 12-inch rolls installed in tandem. The train is driven by a 2000 horse-power motor. The finishing train includes four stands of 10-inch rolls and two stands of 8-inch rolls, which are staggered. The first four stands of this particular unit are driven by a single 1700 horse-power motor through individual spindles geared to the drive shaft of the motor. The last two stands are driven by a 900 horse-power motor. Stock is looped from one stand to another in the finishing train. The 13-inch mill, which produces rounds, squares, flats, and concrete bars of a larger size, consists of ten stands. The first five stands are arranged in tandem, a suitable distance intervening between each stand so that the sections are clear of one stand before entering the other. The other five stands are staggered. Three 1500 horse-power motors drive the ten stands. Two of the motors are connected to the main shaft, driving stands Nos. 1–8; while the third unit drives stands Nos. 9 and 10. The 14-inch mill has ten stands arranged in the same manner at the 13-inch mill. The majority of the heating furnaces are designed to handle 30-foot billets. The furnaces are fired with coke-oven gas, with tar as an auxiliary fuel.

R. A. Fiske, *New Hot-Strip Mill in Operation* (Iron Age, July 8, 1926, vol. 118, pp. 78–81). An illustrated account of the strip mill recently erected at the plant of the Acme Steel Co., Riverside, Illinois. There are fourteen stands driven by nine motors and constituted as follows: seven stands in the roughing mill, three in the intermediate mill, and four in the finishing mill. Two slab-heating furnaces of the recuperative type are provided. Each furnace is designed for a capacity of 15 tons per hour and is sufficiently wide to take slabs 11 feet long. The furnaces are fired by producer-gas, and recuperators are provided

for preheating the air to about 1300° F. The same plant is described by E. C. Barringer, *Increases Stripmaking Capacity* (Iron Trade Review, July 8, 1926, vol. 79, pp. 71–75).

The Experimental Rolling-Mill at the Breslau Technical High School (Stahl und Eisen, July 22, 1926, vol. 46, pp. 986–987). The Institute for the investigation of the practical deformation of metals, especially of the rolling-mill process, was lately formally handed over to the Breslau Technical High School, and forms one of its departments. This testing institute is the only one of its kind in Europe. The experimental mill is of the three-high type, with rolls 450 millimetres in diameter and 800 millimetres in length of surface (about 18 and 32 inches respectively). It is driven by two direct-current motors of 60 and 75 horse-power each, with a current of 220 volts. The plant includes an electric arc furnace and a small Siemens regenerative furnace, with pyrometers and all accessories, a 7-ton crane, a roll-turning lathe, a hydraulic press, cold saw, and cold rolls. An illustrated description of the plant is given.

A. Nöll, *Improvements in Cooling Beds for Light Rolled Sections* (Stahl und Eisen, Aug. 12, 1926, vol. 46, pp. 1077–1083). Describes an improved design of cooling bed in connection with mills rolling small sections, by the use of which economies in power and labour are possible.

The Doubling of Thin Sheets (Stahl und Eisen, Sept. 2, 1926, vol. 46, pp. 1194–1195). In order to roll down sheets to very small thicknesses, it is usual to double them into several layers and cut them at the fold. A new automatic doubling machine for the quicker and better performance of the doubling operation is illustrated and described.

Upcut Shear Affords Even Edges (Iron Trade Review, July 29, 1926, vol. 79, pp. 255–257). Several designs of upcut bloom shears are described, which make possible the use of a stationary table instead of a depressing table.

Shearing Machine for 8-Inch Billets (Engineer, July 30, 1926, vol. 142, p. 125). Illustrated description of the machine built by Henry Pels & Co. It is designed for a continuous shearing pressure of 1500 tons. The shear blades are 28 inches long and have a stroke of $7\frac{7}{8}$ inch. With 30-ton steel, round billets 9 inches in diameter or square billets 8 inches wide may be cropped off with ease. Flats 26 inches wide by $3\frac{5}{8}$ inches thick, or 20 inches by $4\frac{1}{8}$ inches, may be cut off with equal facility.

100-Ton Plate Ripping Machine (Machinery, June 3, 1926, vol. 28, pp. 245–247). An illustrated description of the machine erected at the Redcar Works of Dorman, Long & Co., Ltd., for ripping the steel plates to be used in building the Sydney Harbour Bridge. The largest plate that can be dealt with is 67 feet long by 5 feet wide.

Rolling of Steel.—W. Tafel, *The Theory and Practice of Rolling Steel* (Iron Trade Review, 1926, vol. 78; May 13, pp. 1253–1256; May 27, pp. 1367–1369, 1378; June 10, pp. 1495–1498; June 24, pp. 1626–1629; vol. 79, July 8, pp. 76–79; July 22, pp. 196–199; Aug. 5, pp. 313–315; Aug. 19, pp. 436–437, 446). The continuation of a series of articles on

the principle and practice of rolling iron and steel (*see also* this Journal, 1926, No. I. p. 595).

A. A. Golovin, *Principles of a Theory of Rolling and of Roll Draughting* (Journal of the Russian Metallurgical Society, 1925, pp. 114–139; Revue de Métallurgie, Extraits, 1926, vol. 23, pp. 188–191). The author presents the results of a study of the following principal factors in producing deformation by rolling: the intermolecular friction during plastic deformation; the law of the flow of particles in the pressure zone; the starting-point of deformation in rolling; the mathematical determination of elongation and spreading; dependence of the elongation on the grip of the rolls; the thickness and temperature of the billet and the roll pressure.

C. Schmitz, *Comparative Investigations of Power Requirements and Efficiency of Cogging-Mills* (Stahl und Eisen, June 10, 1926, vol. 46, pp. 769–776). The factors which influence the power requirements of rolling-mills in terms of the elongation of the material have been studied. The time of idle running is shortened by the use of driving motors of large capacity, motors of ample power for roll adjustment, and electrically operated tilting gear instead of hydraulic gear. Further, the output per kilowatt-hour is improved by using taller ingots of a smaller cross-section. Attempts to increase the weight of output by using ingots of a larger cross-section lead to an increase in power consumption per ton of ingots rolled. Curves also show the effect of temperature on the power requirement in terms of the elongation.

C. E. Davies, "*Spread*" *of Metal in Rolling* (Engineer, 1926, vol. 141; June 11, pp. 598–600; June 18, pp. 626–627). So far no satisfactory method of determining the amount of spread during rolling has been evolved. The friction between the rolls and the metal must be a powerful factor in governing this phenomenon, and offers an explanation of the buckling which occurs when sections of hard metal are rolled to fine gauges. In his experiments the author found no constant value for the ratio "percentage reduction to percentage spread," but he found that the ratio of the perimeters of the section before and after rolling were much more nearly constant, though the numerical value varied with the material, with the number of passes used to effect the rolling, and with the shape of the section before and after rolling. The nature and conditions of the metal rolled, and the diameter of the rolls used, had only a very slight effect;. the roll speed had no effect, but the spread did increase with the draught The experiments were restricted to cold-rolling round, square, and comparatively narrow rectangular sections to flat strips.

Rolled Steel Truck Wheels (Iron Age, July 1, 1926, vol. 118, pp. 9–11). An illustrated account of the production of truck wheels as carried out at Bethlehem. Wide flanged I-beams produced in a Grey mill are passed through successive punching, forming, welding, sizing, and drilling operations, and wheels are produced lacking only the hub and the tire. Practically the whole of the operations are carried out by cold-working. The web of the beam is punched out to form the spokes,

the top and bottom halves of the beam each forming a wheel after bending.

C. B. Huston, *Cold-Rolling Imparts Hardness* (Iron Trade Review, July 29, 1926, vol. 79, pp. 251–253). A brief discussion of the operation of strip mills and the production of cold-rolled steel strip. For low-carbon steel four passes between rolls is the maximum number that can be given without annealing. This has led to the practice of operating four stands as a group in tandem. The total reduction that can be made in four continuous passes, or for each annealing, is about 50 per cent.

C. B. Huston, *The Cold-Rolling of Strip Steel* (General Electric Review, 1926, vol. 29, pp. 386–393). Details are given of the cold-rolling, coiling, and pickling operations.

J. A. Coyle, *Making High Grade Steel XII.* (Iron Trade Review, July 1, 1926, vol. 79, pp. 5–7). A brief discussion of the types of cold-rolled steel strip and improvements in its production.

Tube Manufacture.—*Making 50-Foot Tubes from Ingots* (Iron Age, Sept. 23, 1926, vol. 118, pp. 846–850). An illustrated description of the tube plant at Allenport, Pa., where tubes are produced direct from ingots without any preliminary rolling. Ingots are cast in round moulds of various diameter and are broken to the required lengths in a hydraulic breaker. Two continuous furnaces are used for heating the billets prior to piercing, where they are brought to a temperature of about 2500° F. A Mannesmann piercing mill serves two Pilger mills. The Mannesmann mill is driven by a 2250 horse-power motor, and the Pilger mills by a 2000 horse-power motor. After leaving the Pilger mill the tube is reheated in a furnace capable of accommodating tubes 50 feet in length, and fired with natural gas. The tubes are then passed through polishing and sizing mills. The entire mill, which is driven by electric power, has been planned so that material moves continuously in one direction. The same plant is also described elsewhere, *Seamless Tube Mill Employs Forging Rather than Rolling Principle* (Iron Trade Review, Sept. 23, 1926, vol. 79, pp. 773–776).

O. Hock, *The Tube Industry as seen by an American* (Revue Universelle des Mines, July 1, 1926, vol. 11, pp. 34–39). A translation in French in extract of two articles by P. Cebrat which appeared in Iron Age (*see* Journal of the Iron and Steel Institute, 1926, No. I. pp. 596–597).

Coated Steel Pipe made in England by a New Process (Iron Age, Apr. 15, 1926, vol. 117, p. 1065). The South Durham Steel and Iron Co., West Hartlepool, have recently completed a new plant for the manufacture of pipes under a process patented by B. Talbot. This process provides for a hydrocarbon lining which is applied to the pipes centrifugally, either on the inside or outside as desired. The plate used for the manufacture of the pipes is rolled with a diamond checker, or other suitable pattern, to form an anchorage for the lining material.

FURTHER TREATMENT OF IRON AND STEEL.

Cementation and Case-Hardening.—A. Johansson and R. Von Seth, *The Carburisation and Decarburisation of Iron, and Some Investigations on the Surface Decarburisation of Steel* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 295).

A. Bramley and A. J. Jinkings, *The Gaseous Cementation of Iron and Steel. Part I.—Cementation by Carbon Monoxide* (*Iron and Steel Institute:* Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 17–69).

A. Bramley and G. H. Beeby, *The Gaseous Cementation of Iron and Steel. Part II.—Cementation with the Nitrogenous Vapours of Pyridine and Methyl Cyanide* (*Iron and Steel Institute:* Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 71–125).

A. Bramley and A. J. Jinkings, *The Diffusion of Carbon and Nitrogen into Iron and Steel. Part I.—Diffusion of Carbon* (*Iron and Steel Institute:* Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 127–153).

A. Bramley, *The Diffusion of Carbon and Nitrogen into Iron and Steel. Part II.—Diffusion of Carbon and Nitrogen* (*Iron and Steel Institute:* Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 155–174).

The first of these four papers contains the results of experiments made to determine the effects on the resulting cementation produced by variations of the following factors: (*a*) The rate of flow of the carbon monoxide gas through the furnace; (*b*) the period of carburisation; (*c*) the temperature of carburisation; and (*d*) the original carbon content of the steel. Graphs and micrographs showing the variation in degree and manner of penetration of the carbon are reproduced. No evidence of the phenomenon of "liquation" as described by Giolitti was found.

The second paper deals in a similar manner with corresponding experiments in which the cementing gas was carbon monoxide saturated with the vapours of pyridine or methyl cyanide. The relative distribution of the nitrogen and carbon was also studied; the micrographs indicate that the presence of nitrogen reduces the amount of carbon in the steel of eutectoid composition, and tends to preserve the iron in the γ-state. The two last papers deal with the physico-chemical laws governing the experiments described in the first two reports. The application of Fick's law is attempted, and the diffusivity constant of carbon is shown to be affected only by change of temperature. Nitrogen diffuses similarly to carbon and obeys the same laws. Bramley suggests that the evidence derivable from the diffusivity constants and

from X-ray observations of the distribution of carbon in steel offers strong support for the theory of solid diffusion, although probably the whole of the diffusing elements enter the steel originally by chemical reactions resulting from collisions of gaseous compounds with the metal.

P. Henry, *Metallic Cementation and its Industrial Applications* (Revue Générale des Sciences, July 31, 1926, vol. 37, pp. 431–438). The author discusses the laws regulating the phenomenon of cementation; he shows that it is a phenomenon of diffusion, and that, provided three conditions prevail, it will always occur. He then studies the cases where the "contacts" are solid-gas, solid-liquid, and two solids, and describes briefly various industrial processes of cementation. He finally indicates some of the directions in which cemented articles are being, or may be, utilised; these uses all depend, in general, on some property conferred on the skin of the base metal, such as hardness, resistance to wear, or to corrosion, &c.

J. Cournot, *Metallic Cementation and the Coating of Iron Alloys by Aluminium* (Revue de Métallurgie, Mémoires, Apr. 1926, vol. 23, pp. 219–232). The author first reviews the metallic cementation of metals and alloys in general, and then goes on to deal in particular with the coating and cementation of iron alloys with aluminium. A variety of industrial processes in use for this purpose were tried, and the results of the experiments and the conclusions to be drawn are discussed; Martin's process of cementation in an atmosphere of aluminium chloride at 900° to 1000° C., and Meker's process of cementation by packing in ferro-aluminium (Al_3Fe together with about $\frac{1}{2}$ per cent. ammonium chloride) and heating to 900° or 1000° C. (very similar to the ordinary carburisation process), gave the best results, Meker's process being even better than Martin's. Meker's process was therefore used in a series of experiments, the object of which was the study of the behaviour and characteristics of the coatings resulting from variations in the conditions of the experiments. The results of these experiments are set out in full and illustrated by micrographs.

J. Laissus, *Contribution to the Study of Metallic Cementations. Cementation of Iron Alloys by Tungsten* (Revue de Métallurgie, Mémoires, Apr. 1926, vol. 23, pp. 233–242). (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 600.)

Metallic Cementation (Metallurgist, July 30, 1926, pp. 111, 112). An English abstract of three papers published in Revue de Métallurgie by Laissus (Mar. 1926, p. 155; *see* Journal of the Iron and Steel Institute, 1926, No. I. p. 599), by Cournot in the April number (p. 219), and by Laissus also in the April number (p. 233).

W. J. Merten, *Irregular Carburisation of Iron and Iron Alloys—The Cause and Prevention* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 907–928, 1004). The author deals with the factors governing successful carburising practice, and discusses the physico-chemical reactions in the carburising container.

It is shown that the composition of the steel plays only a minor rôle in the production of a proper depth and uniformity of case, and that the physical structure of the steel, and the mechanical arrangement of the steel articles and carburisers for correct chemical reactions, are the main factors.

Carburising Piston Rods and Long Tubes (American Machinist, European Edition, Oct. 23, 1926, vol. 65, pp. 491–492). For carburising piston rods, drill rods, and steel tubing, gas-fired rotary-retort furnaces are used by the American Metal Treatment Co. The work is supported on "spiders" so as to prevent sagging, and a gas (unspecified) is used as the carburising medium. A gas-fired furnace 24 feet long is used for annealing; and uniformity of temperature is obtained by subdividing the gas supply, each section being regulated by heat controllers of the Machlet type. The latter furnace is also suitable for hardening and tempering.

S. P. Rockwell, *Rotary Carburising* (Machinery, Sept. 9, 1926, vol. 28, pp. 677–679). This article also describes the rotary carburising furnaces referred to above.

J. B. Nealey, *Reducing the Cost of Carburising Transmission Gear Stock* (Iron Trade Review, June 3, 1926, vol. 78, pp. 1431–1433). Particulars are given of the design of two oil-fired carburising furnaces for the treating of automobile parts. The furnaces are 25 feet in length and have two zones, one for direct heating and one for soaking in a muffled chamber. Each furnace is equipped with four oil-burners, and provision is made for the use of gas if required.

L. Guillet, *Cementation of Steel by Silicon* (Comptes Rendus, 1926, vol. 182, pp. 1588–1589). The author shows that in the presence of ammonium chloride the cementation of steel by ferro-silicon containing 75 to 80 per cent. silicon takes place very rapidly at temperatures ranging from 1100° to 1200° C. The surface layer contains about 15 per cent. of silicon and is very brittle.

Case-Hardening with Nitrides (Metallurgist, Apr. 30, 1926, pp. 60–61; Iron Age, Aug. 5, 1926, vol. 118, pp. 340–341). An illustrated account of Fry's process of case-hardening translated from the original article which appeared in Kruppsche Monatshefte, Feb. 1926. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 600.)

G. Grube and W. von Fleischbein, *Surface Improvement of Metals by Diffusion ; Diffusion of Chromium into Iron* (Zeitschrift für anorganische Chemie, 1926, vol. 154, pp. 314–332). When an iron bar is embedded in powdered chromium and heated in hydrogen, the chromium penetrates the surface of the iron, the depth of penetration increasing with rising temperature and duration of heating. At the end of twenty-four hours at 1100° the depth of penetration is 0·3 millimetre, and the surface layer contains 5·3 per cent. of chromium. After seventy-two hours at 1280° the depth of penetration is 1·7 millimetre, and the chromium percentage is 28·4. After ninety-six hours at 1200° the chromium in the surface layer has increased to 43·3 per cent., and at 1280° and 1320°

it has risen to 47·4 and 52·9 per cent. respectively. The composition then remains constant for a depth of about 0·3 millimetre, showing that the degree of solubility of chromium in iron has probably been reached at the several temperatures. Tests show the protective effect of the chromium against attack with dilute nitric acid.

Heat-Treatment Plant.—A. J. Smith, *Case-Hardening in Gas-Heated Furnaces* (Forging, Stamping, Heat Treating, Aug. 1926, vol. 12, pp. 289–290). The author puts forward figures to show that the application of reversible regeneration to case-hardening furnaces makes the use of gas both satisfactory and economical. No details of the furnace or regenerator are given.

Case-Hardening and Fuel Costs (Iron and Coal Trades Review, July 2, 1926, vol. 113, p. 7). Brief particulars are given of the "Revergen" gas-fired furnace for case-hardening. The furnace is provided with a double system of recuperators, and operates upon town gas at ordinary main pressure, under a slight air pressure provided by a small open-type fan.

H. E. Martin, *Progressive Carburisation in Electric Furnaces* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 933–937). A brief discussion of the limitations of oil-fired carburising furnaces, and a description of a battery of three resistor-type rotary electric furnaces and their operation.

I. S. Wishoski, *Electric Rotary Furnaces Prove Highly Successful* (Fuels and Furnaces, June 1926, vol. 4, pp. 683–688). An illustrated description of the rotary carburising furnaces in operation at the plant of Dodge Bros., Detroit.

A. N. Otis, *Electric Furnaces for Heat-Treating* (Forging, Stamping, Heat Treating, June 1926, vol. 12, pp. 192–196). The article describes some of the electric furnaces installed at the Schenectady plant of the General Electric Co., and the variety of heat-treating work to which they have been adapted. The ageing of iron castings can be accelerated by a suitable heating cycle, and one furnace has been built specially for this purpose. Single castings weighing 67 tons have been treated, but the usual load is about 100 tons of castings. The castings are made of a special iron produced by adding a considerable percentage of steel scrap to the pig-iron charged into the cupola.

P. F. Creasy, *Electric Heat for the Machine Shop* (American Machinist, European Edition, July 10, 1926, vol. 64, pp. 865–868). Describes some of the ways in which electric heating results in better work and improved conditions. All the furnaces described are of the resistance type.

J. L. Munnis, *Rivet Heating in Gas-Fired Furnaces* (Forging, Stamping, Heat Treating, Aug. 1926, vol. 12, p. 295). A description is given of gas-fired rivet heaters which were developed to replace oil-fired furnaces. Besides being more economical to use, the gas-fired furnaces heated the rivets more uniformly, were easier to manipulate, and

produced better shop conditions owing to the absence of oil-leaks and smoke.

I. Ginsberg, *Gas as a Fuel for Heat-Treating Metal* (Forging, Stamping, Heat Treating, July 1926, vol. 12, pp. 250–252). The present article is an introduction to a series dealing with the use of gas for heat-treating.

Heat Treatment and Foundry Plant (Machinery, July 22, 1926, vol. 28, pp. 459–460). A description of a coke-fired muffle furnace, an intensive sand mixer, and a core stove.

A Radiant-Heat Furnace (Gas Journal, Sept. 1, 1926, vol. 175, p. 474). Brief details of a gas-fired radiant-heat furnace are taken from M. Bazenaut's paper read before the Annual Meeting of the Société Technique. The gas and preheated air are intimately mixed and are burnt in narrow "cells" or channels formed in specially shaped refractory bricks; complete combustion takes place within the bricks, no flame entering the furnace proper, and the heating is effected by radiation from the refractory bricks only.

A New Method of Applying Surface Combustion Industrially (Fuel Economist, Feb. 1926, vol. 1, pp. 203–208). An illustrated description of the Krupp radiant brick furnaces for use with clean gas. These furnaces are being used for reheating, forging, welding, and heat treatment. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 602.)

Unusual Tunnel Annealing Furnace (Iron Age, May 20, 1926, vol. 117, pp. 1410–1413). The car-type continuous furnace illustrated and described is in operation at the plant of the North-Western Malleable Iron Co., Milwaukee. It is of the open-fire or semi-muffled type and is fired by high-pressure gas. The tunnel is open at the sides to 14 inches above the floor, the tops of the cars forming the bottom of the oven. This permits a free circulation of air under the cars and renders cooling of car wheels and bearings unnecessary. A pit extends the whole length of the oven under the car track, so that repairs to cars can be carried out without stoppage of the oven. The temperature at the charging door is 650° F., and reaches a maximum of 1700° in the soaking zone. At the discharge end of the oven it is approximately 900°. The over-all length of the kiln is 210 feet, the length of the kiln itself being 180 feet. The gas-burners are arranged thirty-six on either side of the oven.

Automatic Continuous Electric Furnace (American Machinist, European Edition, Sept. 4, 1926, vol. 65, p. 44E). A description of an electrically heated hardening and tempering furnace for continuously treating wire and strip steel as it is fed through the furnace from the roll.

Electric Furnaces at Works of Auto Machinery Co., Ltd. (American Machinist, European Edition, Aug. 21, 1926, vol. 65, pp. 26E–28E). A description is given of electric furnaces and the conditions of their operation, for the automatic hardening of ball-races, the carburising, hardening, and refining of tappets, and the heat treatment of high-speed steel. The latter operation is carried out in carborundum furnaces,

the others being done in resistance-type furnaces. Automatic temperature and current control is installed on the hardening furnace, so that the current is maintained at the correct value for the temperature required and is cut off when the work is finished.

S. Tour, *Salt-Bath Furnaces—Design and Operation* (Forging, Stamping, Heat Treating, May 1926, vol. 12, pp. 173–179). *See* Journal of the Iron and Steel Institute, 1926, No. I. p. 605.

M. Méker, *Remarks on the Subject of the Use of Tempering Baths, and Possible Accidents* (Revue de Métallurgie, Mémoires, Aug. 1926, vol. 23, p. 463). The author draws particular attention to two points which must be watched when using tempering baths which contain alkaline nitrates. The pieces to be introduced must be perfectly dry, and they must have no cyanide or ferrocyanide adhering to them, a mixture of these latter with a nitrate forming a very dangerous explosive. M. Job (pp. 463–464) draws attention to the very powerful oxidising character of the nitrate baths, and points out that some metals even may be oxidised by the bath with sufficient rapidity for an explosion to occur.

Salt Baths Very Successful in Heat-Treating of Dies (Fuels and Furnaces, Sept. 1926, vol. 4, pp. 1084–1086). Particulars are given of the practice at the plant of the Geometric Tool Co., New Haven, Connecticut, where thread-cutting dies and other tools are hardened and tempered in several multiple-pot salt-bath furnaces.

Pyrometry.—M. Waldhausen, *Optical Temperature Measurements* (Fuels and Furnaces, Aug. 1926, vol. 4, pp. 939–940). A discussion of the principles of operation and the application of optical temperature-measuring instruments.

High Temperature Measurements (Engineering, May 28, 1926, vol. 121, p. 626). A review of the various forms of pyrometer, their advantages and disadvantages, and a description of an aspiration pyrometer developed by the Wärmestelle of the Verein Deutscher Eisenhüttenleute Düsseldorf. It follows on the lines of the instrument introduced by the late Dr. Assmann many years ago.

R. A. Ragatz and O. A. Hougen, *Protecting Thermocouples by Transparent Silica Tubes* (Chemical and Metallurgical Engineering, July 1926, vol. 33, p. 415). Whereas translucent fused silica sheaths for thermocouples permit reducing gas at high temperatures to percolate and cause contamination, the experiments recorded in the article showed that transparent fused silica did not do so. Couples of noble metals in the latter type of tube remained quite unaffected. Chromel-alumel couples showed an increase of E.M.F.; the action of reducing gases would have been to lower the E.M.F., and the rise was proved to be due to oxidation of the couple by air enclosed within the tube.

Heat Treatment of Iron and Steel.—H. J. French and O. Z. Klopsch, *Some Characteristics of Quenching Curves* (U.S. Bureau of Standards, 1926, Technologic Paper, No. 313: Transactions of the American

Society for Steel Treating, June 1926, vol. 9, pp. 857–882, 906). The results of previous experiments are summarised (U.S. Bureau of Standards, 1925, Technologic Paper, No. 295), and the results of additional tests are given. The authors discuss the construction of time-temperature cooling curves for the centre of steel samples of various sizes and shapes quenched in ordinary cooling media, such as water, oil, and air. Samples of carbon and carbon-chromium steel were used in the experiments. A method is outlined by which cooling curves for specimens of different dimensions quenched from various temperatures can be derived, provided the curve for one size from one quenching is available and one constant is known for the coolant. Typical examples are given.

J. Hébert, *Quenching Liquids* (Technique Moderne, 1926, vol. 18, pp. 65–71). A discussion of the effects of the composition and temperature of the quenching liquid on the hardness of steels.

S. N. Brayshaw, *Heat Treatment of Tool Steel* (Transactions of the Liverpool Engineering Society, 1925, vol. 46, pp. 126–151). The author describes his investigation of the hardening of tool steel, and points out the importance of a thorough annealing prior to the hardening operation as a means for the elimination of hardening cracks.

L. Balliet, *Notes on Tempering Drill Steel* (Engineering and Mining Journal-Press, May 22, 1926, vol. 121, pp. 843–846). The author points out some of the adverse factors governing the heat treatment of mining drills. He then discusses the heating and cooling of steel, with special reference to the critical range of temperature and the theory of tempering. A reverberatory type of furnace is described ; it is intended for use with oil or gas fuel, but may be adapted to burn solid fuel. It is arranged so that the steel is heated in an atmosphere of burnt gases, the flames not being allowed to strike directly on the metal, so that oxidation is minimised. The heating up is slower, but this is advantageous in eliminating the internal strains generated in the steel during its use in the drilling machines. The author suggests that the blacksmith in the mine should only shape, sharpen, and dress the steels, and pass them on to a specialist for heat treatment.

J. B. Mudge, *The Selection of Proper Material for Tool Manufacture* (Paper presented at a Joint Meeting of the American Society of Mechanical Engineers and the Western Society of Engineers, Chicago, Mar. 24, 1926 : Mechanical Engineering, July 1926, vol. 48, pp. 727–730 ; Forging, Stamping, Heat Treating, Sept. 1926, vol. 12, pp. 335–338). A broad review of methods of inspecting and checking the steel, and of the types of steels to be used for making various kinds of tools.

C. Jones, *Changing the Size of Steel Fittings* (Forging, Stamping, Heat Treating, June 1926, vol. 12, pp. 206–207). It often happens that holes in small fittings, such as collars, taper gauges, &c., are bored out slightly too large ; the article describes a heat-treating method of shrinking the pieces. The object, say a cylindrical piece of steel with an axial hole, is heated to bright redness, and one end only is

water-quenched. This upsets the metal of the other end. The whole is allowed to cool to black heat, is quenched, and is then reheated, quenching the other end, and cooling as before. The quenching strains are then relieved, and the piece hardened or otherwise treated to bring it to the desired condition. In one example quoted an internal diameter of 1⅝ inch was reduced by an average of 0·014 inch.

R. Pritchard, *Double Annealing Prevents Cracked Dies* (Forging, Stamping, Heat Treating, June 1926, vol. 12, p. 220). Two large cast steel rings were required in a hurry. One was forged solid, and the other, owing to shortage of metal, was punched with a hole and expanded to the size required. The centres were cut out with oxy-coal-gas cutting plant, and when that part of the work was done both rings broke. The author considers that if a thorough anneal had been given after the forging operation the mishap would not have occurred, but that and the necessary anneal after cutting would not have been a commercial proposition. He suggests that for this purpose the slower but safer method of cutting out by machine is preferable.

A. J. Porter, jun., *Heat Treatment of Die Blocks* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 447–456). A brief discussion of the hardening of die blocks, and their breakage, due to improper heating and other treatment.

Tentative Recommended Practices for the Heat Treatment of Plain and Alloy Steel Die Blocks (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 477–486). The recommended practices suggested by the Society for the heat treatment of plain carbon and alloy steel die blocks are given in full. Tables are included giving the approximate compositions of die blocks.

J. J. Kauffman, *Hardening-Room Practice* (American Machinist, European Edition, June 19, 1926, vol. 64, pp. 757–758). The author discusses some of the causes of breakages during hardening and suggests remedies. He also outlines in a general way the routine of hardening, adding a few words on equipment. He gives a list of hardening and drawing temperatures for use with different carbon steels for different purposes.

J. H. Andrew and H. A. Dickie, *A Physical Investigation into the Cause of Temper Brittleness* (Paper read before the Iron and Steel Institute, Aug. 1925: this Journal, p. 359).

H. C. Knerr, *Heat Treatment and Metallography of Steel* (Forging, Stamping, Heat Treating, 1926, vol. 12; Apr., pp. 127–131; June, pp. 212–219; Aug., pp. 275–279, 283; Sept., pp. 339–343). The continuation of a serial (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 647). A practical course in the physical metallurgy of iron and steel, describing all operations in the heat treatment of steel. The underlying theory of the practical processes of manufacture is discussed. In the present articles special alloying elements—chromium, vanadium, nickel, silicon, and manganese—are dealt with.

H. M. Boylston, *The Heat Treatment of Steel* (Fuels and Furnaces,

Sept. 1926, vol. 4, pp. 1035–1066). The subject is discussed under the following headings: Annealing of forged and rolled carbon steel objects, annealing of cold-worked objects, annealing of steel castings, annealing of tool steel, high-speed steel and special steels, furnaces for annealing, toughening instruments, hardening, tempering, carburising and case-hardening, heat treatment of case-hardened objects, burning and surface decarburisation.

H. B. Knowlton, *Facts and Principles concerning Steel and Heat Treatment.—Part VI.* (Transactions of the American Society for Steel Treating, May 1926, vol. 9, pp. 781–792). The author discusses some of the difficulties arising in the hardening of steel. Distortion, warpage, and cracking are dealt with, and the changes in shape and volume, the effect of the composition of the steel, temperature, and the different methods of heating and of quenching are also discussed.

H. B. Knowlton, *Facts and Principles Concerning Steel and Heat Treatment.—Part VII.* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 954–965). The author discusses several methods of producing a variation in the hardness, toughness, and other physical properties of different portions of the same steel. Differential heating, differential quenching, and differential drawing are described. A brief discussion of the effect of the different methods on the gradation zone between hard and soft areas is also given.

H. B. Knowlton, *Facts and Principles Concerning Steel and Heat Treatment.—Part IX.* (Transactions of the American Society for Steel Treating, Oct. 1926, vol. 10, pp. 638–656). This article covers the fundamental principles of normalising, annealing, hardening, tempering, and heat-treating of low and medium carbon steels. The use of critical range diagrams and charts giving physical properties produced by different heat treatments are explained. Photomicrographs are included to show the effects of different heat treatments upon the structure of the steel.

J. Trantim, jun., *Effect of Heat Treatment on Nickel Steel* (Forgnig, Stamping, Heat Treating, Aug. 1926, vol. 12, pp. 293–294). Data on the physical properties of rolled electric nickel steel, heat-treated by quenching in water and drawing at various temperatures, are tabulated.

Heat Treatment for Nickel Steels (American Machinist, European Edition, 1926, vol. 64; June 5, p. 683; July 31, p. 993). In the first note the heat treatments for annealing and hardening various nickel and chrome-nickel steels for various purposes are tabulated, and in the second the treatment for carburising and case-hardening similar steels are recorded in the same manner.

B. Egeberg, *How to Treat Manganese Steel* (Iron Age, Sept. 9, 1926, vol. 118, pp. 676–678). The author deals with the heat treatment of manganese steel in both the forged and cast condition. Brief particulars are also given of its manufacture.

Second Report of the Gas Cylinders Research Committee (*Periodical Heat Treatment*) (Department of Scientific and Industrial Research,

London, 1926: Engineering, Aug. 6, 1926, vol. 122, pp. 184, 185). This publication reports the results of tests carried out at the National Physical Laboratory to determine the effects of re-annealing and of renormalising overstrained specimens of 0·25 and 0·45 per cent. carbon steels. The experiments were carried out to ascertain whether it was necessary for steel gas cylinders to undergo periodical heat treatment. In view of the experiments, the Committee agree that the results indicate that the periodical reheat treatment of carbon steel gas cylinders which have not been obviously damaged serves no useful purpose, and they recommend that the practice be discontinued. The following reports are appended: *Report on Tests on the Effect of Periodical Heat Treatment on Samples of Carbon Steels*, by A. Bailey, E. W. Colbeck, and P. L. Thorpe; *Report on Tests made to Determine whether any Embrittling takes place in Steel due to Repeated Hammering Upon the Surface*, by A. Bailey and D. Hanson.

L. E. Everett, *Electric Heat-Treating of Steel Castings* (Electrical World, 1926, vol. 87, pp. 1233–1236). The practical advantages of electric furnaces over fuel-fired furnaces are pointed out, and a semi-recuperative electric furnace is described and illustrated.

A. E. White, *Heat-Treatment Data on Quality Steel Castings* (Mechanical Engineering, May 1926, vol. 48, pp. 497–500; Forging, Stamping, Heat Treating, May 1926, vol. 12, pp. 164–168). *See* Journal of the Iron and Steel Institute, 1926, No I. p. 609.

O. D. North, *Heat-Treated Bolts* (Automobile Engineer, July 1926, vol. 16, pp. 252–253). The author discusses the merits of heat-treated bolts, and their superiority over the ordinary untreated variety. The most vital requirement in a bolt is a high elastic limit coupled with a good elongation figure. A bolt with an ultimate strength of 45 tons per square inch, an elastic limit of 30 to 35 tons per square inch, a fairly high percentage elongation, and a good Izod impact figure, can be made from a good carbon steel suitably heat-treated after manufacture, and is a great advance on the present-day commercial bolt.

A. C. Burgoine, *Heat-Treated Bolts* (Automobile Engineer, Aug. 1926, vol. 16, pp. 299–300). A few notes on the use of various steels and alloy steels for the manufacture of bolts for automobile construction.

Annealing Sheet Steel at High Temperature without Scaling (Iron Trade Review, Sept. 2, 1926, vol. 79, pp. 571, 623). Brief particulars are given of a furnace developed by the International Furnace Co., Pittsburgh, for the annealing of sheets. The sheets are heated to 1800° F. or higher, and cooled in the furnace to 1400° F. when they are discharged and cooled in air. The furnace, which is continuous, is 70 feet long, and has a capacity of 120 tons per twenty-four hours. The temperature is automatically controlled.

F. C. Hudson, *Heat-Treating Axle Shafts by Special Machinery* (American Machinist, European Edition, Oct. 23, 1926, vol. 65, pp. 485–486). The plant described consists of two round electric furnaces and two quenching tanks. The axles are handled by compressed air machinery, and move through the furnaces at a speed which brings

them opposite the opening for removal at the correct time. The temperature of the quenching tanks is also automatically controlled.

L. C. Morrow, *Heat-Treating "Caterpillar" Parts* (American Machinist, European Edition, Oct. 23, 1926, vol. 65, pp. 477–480). Owing to the severe shocks and abrasion experienced by working parts of tractors, particularly in the track and track-driving mechanism, the heat treatment must be of a very high order. A brief description, with illustrations, of the heat treatment and testing equipment of the Caterpillar Tractor Co. is given.

C. H. Carpenter, *Heat-Treating Axe Bits by Electricity* (American Machinist, European Edition, Oct. 23, 1926, vol. 65, pp. 481–483). The Kelly Axe and Tool Co. have installed twenty-three heat-treating furnaces for hardening and drawing operations in their small-tool department; they are all of the electrically heated lead bath type, the most valuable property of which is the very rapid heat-transference to the object under treatment.

F. H. Colvin, *Where Heat Treatment Increased the Life of Machines* (American Machinist, European Edition, Oct. 23, 1926, vol. 65, pp. 473–475). The author describes briefly the heat treatment and inspection given to certain small parts turned out in large quantities which were subject to much wear.

Normalising and Annealing (Machinery, Sept. 30, 1926, vol. 28, p. 791). The distinction between normalising and annealing, both as regards the method adopted and the characteristics of the steel after the treatment, is made clear. The effects of normalising are briefly related, and it is pointed out that a desired result may sometimes be more economically attained by normalising than by oil-quenching and tempering, whereas in other cases the reverse may hold good.

Heat-Treatment Practice (Automobile Engineer, July 1916, vol. 16, pp. 262–263). A review of the chemical and physical considerations underlying correct heat treatment.

Steel House Construction.—H. Blecken, *Steel Houses* (Stahl und Eisen, Aug. 12, 1926, vol. 46, pp. 1085–1087). Reference to the proposals and plans for the construction of steel houses in Great Britain is made, and some illustrations and designs are shown of similar houses which it is proposed to erect at Duisburg.

Automobile Parts.—T. H. Wickenden, *Selecting the Proper Steels for Use in Automobile Parts* (Iron Trade Review, Sept. 2, 1926, vol. 79, pp. 566–567, 571). The nickel and nickel-chrome steels are widely used and satisfy most requirements in automobile construction. The use of 3·5 and 5 per cent. nickel steels is recommended for such parts as steering-knuckle pins, steering-arm balls, steering-gear parts, wrist pins, camshafts, case-hardening gears, and shafts and bolts which are intended for spring assemblies. For forged structural parts chrome-nickel steel is recommended.

Springs.—T. M. Jasper, *Factors of Design of Shock-Absorbing and Recuperating Steel Springs* (Mechanical Engineering, May 1926, vol. 48, pp. 487, 488). This paper was presented under the title "*An Outline for the Application of Fatigue and Elastic Results to Metal Spring Design*" to the American Society of Mechanical Engineers, Nov. 30 to Dec. 4, 1925. The author divides the problem of spring design into two parts, and considers (*a*) the static elastic and fatigue properties of the material to be used, and (*b*) the shape of the springs and the distribution of the stresses developed in their use for a given deformation.

Welding and Cutting.—*Recent Improvements in Welding Processes* (Metallurgist, June 25, 1926, pp. 95–96). Abstract of three articles in General Electric Review for March 1926, by Langmuir, Weinmann and Langmuir, and Alexander. (For the latter *see also* Journal of the Iron and Steel Institute, 1926, No. I. p. 611.) The first two authors deal with a method of welding employing "atomic" hydrogen. The gas is blown from a small tube through an electric arc, and the flame produced by this atomic hydrogen is much hotter and more chemically active than that produced by burning molecular hydrogen or acetylene. Molybdenum melts with ease at a distance of 1 to 2 cm. from the arc, and near the edge of the arc tungsten rods can be melted. Contamination of the work by carbon, oxygen, or nitrogen is of course prevented. Special welding torches are used, and a higher voltage than usual is necessary to strike the arc in the hydrogen atmosphere. Sufficient gas is used at such a pressure that the work is bathed in hydrogen. *See also* abstracts in Chemical and Metallurgical Engineering, May 1926, vol. 33, pp. 286–287, and Metal Industry, June 18, 1926, vol. 28, pp. 577–578.

Welding in an Atmosphere of Hydrogen (Forging, Stamping, Heat Treating, Apr. 1926, vol. 12, pp. 136–139). This article gives more details of the methods of arc welding in an atmosphere of hydrogen gas devised by Langmuir and Alexander referred to above. Two types of atomic hydrogen torch, and examples of various tests carried out on welds made in a hydrogen atmosphere, are illustrated.

S. M. Norwood, *The Welding of High-Chromium Alloys intended to Meet Extreme Conditions* (Paper read before the American Electrochemical Society, Oct. 1926). There are many difficulties inherent in the welding of alloys containing more than 10 per cent. of chromium. The most serious are those of brittleness in the weld and in the base metal adjacent to the weld. These can be overcome by the addition of 8 per cent. of nickel to high-chromium alloys. Nickel, however, has a tendency to diminish the corrosion-resisting properties of the alloy to certain media, such as sulphur and gases containing sulphur. This objection is offset by increasing the silicon in the alloy to about 2 per cent. The presence of manganese in percentages equal to the silicon improves the welding characteristics of the alloy.

G. L. Walker, *Welding Carbon and High-Speed Steels* (Forging,

Stamping, Heat Treating, July 1926, vol. 12, pp. 255–258). A paper presented before the American Welding Society, New York Section, on May 18, 1926. In welding high-carbon and high-speed steels the torch should give a very thoroughly mixed gas mixture with a low gas ratio. The flame should never be oxidising in character, but whereas the lower carbon steels may be welded in a neutral flame, the higher-carbon steels need an excess of acetylene in the flame. A smaller tip than usual is used. The welding rod should be of high grade material with not less carbon in it than in the steel to be welded; it is sometimes advantageous for the welding rod to contain rather more carbon than the part to be welded. The bevel should be wider for tool steel than for low-carbon steel, and thorough cleaning is essential. The work must not be overheated, and oxides and blowholes are to be avoided. A flux is almost a necessity. By this process broken cutting edges can be repaired, or high-speed cutting edges may be built up on shanks of low-carbon steel; there are many other uses for the process besides.

E. Höhn, *Autogenously and Electrically Welded Boilers and Containers* (Zeitschrift des Vereines deutscher Ingenieure, 1926, vol. 70; Jan. 23, pp. 117–122; Feb. 6, pp. 194–196; Metallurgist, Apr. 30, 1926, p. 56; Mechanical Engineering, June 1926, vol. 48, pp. 603–609). A paper presented to the General Union of German Steam Boiler Inspection Associations. The increasing use of welding has led to the investigation of the strength and tenacity of parts welded together. Welded joints are now known to be stronger than riveted joints. The author proposes a new method of safeguarding welded seams by straps welded on.

M. Roux, *The Repair of Manganese Steel Railway Track Mechanism by Autogenous Welding* (Revue de Métallurgie, Mémoires, Apr. 1926, vol. 23, pp. 243–250). The author describes experiments and tests made to discover the way to apply autogenous welding to the repair of manganese steel. He then relates how the repair of actual pieces of railway track, such as cross-overs and similar parts subject to heavy wear, or overloading leading to cracks, was attempted. The method presents considerable difficulties on account of the internal stresses in the metal, but, by taking the precautions described in the article, the author considers that the repair of manganese steel pieces by autogenous welding is possible.

S. W. Miller, *Unsolved Fundamental Gas Welding Problems* (Paper read before the American Bureau of Welding, Apr. 1923, 1926).

E. E. Thum, *Design of Oxwelded Equipment* (Paper read before the American Welding Society, Apr. 22, 1926).

P. L. Roberts, *Electric Welding* (Electrician, May 28, 1926, vol. 96, pp. 544–545). The principles of the various methods of welding are described and their merits compared. An outline of the many applications to which welding may be put is given.

H. von Neuenkirchen, *Electric Arc-Welding in Mining* (Glückauf, June 12, 1926, vol. 62, pp. 770–773). Describes apparatus specially designed for arc-welding of broken parts of colliery machinery and

equipment. For such repair work the electric welding process has proved to be of great utility, and a number of examples of its application are shown.

Electric Welding Facilitated by Copper-Tungsten (Engineering and Mining Journal-Press, May 15, 1926, vol. 121, p. 800). One of the limiting factors in many resistance or spot welding operations is the copper electrode; after a few welds have been made it becomes annealed by the heat of the welds and then rolls and mushrooms over the edges, producing unsatisfactory work. Copper-tungsten combines the properties of a good conductor with a hard metal; its hardness is 225 Brinell, as compared with 82 for hard copper and 30 for soft copper, and its other mechanical properties are also superior to copper. It does not anneal at red heat. It is more expensive than copper, but it is not necessary to form the whole electrode of the alloy. It has been given the name Elkonite.

P. Schimpke, *Autogenous and Electric Welding of Iron Castings* (Stahl und Eisen, Aug. 26, 1926, vol. 46, pp. 1141–1148). The author describes the appliances in use for autogenous and electric welding. A number of practical examples are given of hot and cold welding of castings by both processes, and it is now established that welding can be easily and successfully applied for the repairing of broken castings.

W. L. Warner, *Commercial Arc Welding Applications* (Iron Age, Aug. 12, 1926, vol. 118, pp. 421–422). A brief description of the many applications of electric arc welding. These include the construction of gas-holders, large pipes, and gas mains.

The Electric Welding of Structural Steel (Electrical Review, Sept. 24, 1926, vol. 98, pp. 513–514). A note on some experiments carried out by J. M. Daniels at the Carnegie Institute of Technology to demonstrate that steel structures could be built up by electric welding, and joints produced that would not fail even when loaded up to the rupturing loads of the structural members themselves.

J. H. Edwards, *Welding in the Structural Field* (Paper read before the American Bureau of Welding, Apr. 23, 1926: Iron Age, Apr. 29, 1926, vol. 117, pp. 1195–1196).

J. Caldwell, *Electric Welded Construction* (Paper read before the Institution of Welding Engineers: Electrical Review, Apr. 23, 1926, vol. 98, pp. 678, 679). A description of the strength properties of electric welds and a review of their advantages and application in constructional and repair work.

P. Alexander, *Arc Welding in Hydrogen and other Gases* (Paper read before the American Welding Society, Apr. 22, 1926). The author describes a new method of arc welding in a hydrogenated atmosphere.

S. Halas, *Practical Electrical Welding* (Electrician, Oct. 1, 1926, vol. 96, pp. 388–390). The author discusses the practical and commercial advantages of electric welding.

New Welding Dynamo of Unusual Design (Machinery, Apr. 29, 1926, vol. 28, pp. 154–155). Greater efficiency is claimed for this machine owing to the absence of the controlling devices usually neces-

sary for welding dynamos. It is of the drooping characteristic type, and all the control is brought about by the unusual arrangement of the poles and windings. The open circuit voltage is 45 volts, which drops to the arc voltage during welding. The machine is self-stabilising, and as there is no time-lag due to the windings no reactor is necessary as in shunt machines. It is also self-exciting. The short circuit voltage is not felt when the terminals are held in each hand on full load. These dynamos are possibly unique in that they can be run in parallel if necessary.

A Portable Arc-Welding Plant (Engineer, May 28, 1926, vol. 141, p. 562). An illustrated description of a new portable arc-welding plant manufactured by Siemens-Schuckert, Ltd. The whole is contained in a single housing and is claimed to be specially suitable for outdoor work. The welding current may be varied between 100 and 200 amperes, and the pressure between 20 and 45 volts, open circuit pressure being 95 volts, which is suitable for striking the arc when using flux-covered electrodes. The design allows the voltage to rise quickly after a short circuit without a sudden rush of current.

A Controller for Electric Arc Welding (Engineering, Aug. 6, 1926, vol. 122, pp. 176–177). The object of this apparatus is to enable arc welders to work with a low voltage for striking and maintaining the arc while drawing current from high voltage sources of supply. This is attained by the use of suitable resistances and an automatic switch; a by-pass circuit of equal resistance to the normal welding circuit is cut "out and in" according to whether the welding circuit is complete or broken.

Electric Arc Welding in the Foundry (Foundry Trade Journal, Sept. 30, 1926, vol. 34, pp. 287–289). Types of arc welding sets suitable for use in the foundry for the repair of castings are described and illustrated.

P. L. Roberts, *The Welding of Defective Work in the Machine Shop* (Machinery, July 29, 1926, vol. 28, pp. 502–504). A discussion of the application of welding to the repair and recovery of defective parts. The methods to be adopted and precautions to be taken when welding steel, cast-iron, and non-ferrous metals are detailed. Faults, whether due to bad foundry work or to defective machining, are alike often amenable to this method of correction.

J. W. Owens, *Design of Welded Joints in Ship Construction* (Paper read before the American Welding Society, Apr. 22, 1926). Automatic arc welding machines permit of butt welding at a high rate of speed, and thereby minimise thermal stresses. Thermit welding is, in the author's opinion, preferable to smith welding for the construction of stern frames and the frames of large rudders. The application of gas welding to the construction of tanks and pipe-fittings is considered good practice. Metal arc welding can also be used for this purpose.

S. W. Miller, *Design of Welded Joints* (Paper read before the American Welding Society, Apr. 22, 1926).

H. H. Moss, *Welded Structural Steel Work* (Chemical and Metallurgical Engineering, Sept. 1926, vol. 33, pp. 540–542). The design of the welded joints for the manufacture of structural steel work and the welding procedure are described.

A. C. Vick, *Design of Welded Tanks* (Paper read before the American Welding Society, Apr. 22, 1926).

L. H. Burkhart, *Design and Manufacture of a Horizontal Cylindrical Pressure Tank* (Paper read before the American Welding Society, Apr. 22, 1926). Steps in the design and manufacture of an electrically welded tank for use as an air or steam receiver under 250-lb. working pressure are outlined.

L. J. Sforzini, *Welding in the Design of Industrial and Power Piping* (Paper read before the American Welding Society, Apr. 22, 1926). The principles involved in the design of welded piping are dealt with.

A. O. Miller, *Fabricating Heavy Equipment by Welding* (Paper read before Associated Technical Societies of Cleveland, May 10–15, 1926: Chemical and Metallurgical Engineering, July 1926, vol. 33, pp. 410–411). A description of the manufacture of a rotary lime kiln and four large pressure tanks. Careful tests and calculations showed that thinner steel plates could be used with welded joints than with rivets, and in the case of the kiln there was the further advantage that the alternation of stresses during rotation has no effect on the welds, whereas rivets tend to work loose.

Crane Runway Built by Welding (Iron Age, Apr. 22, 1926, vol. 117, pp. 1132–1133). The application of electric arc welding to the construction of a crane runway is described and illustrated. The runway is 245 feet long, and was built for a 10-ton crane having a 100-foot span; 65 tons of steel were used in its construction for the supporting members and crane girders.

F. P. Wilson, jun., *Cutting Torch Burns Illuminating Gas* (General Electric Review, June 1926; Iron Trade Review, Aug. 12, 1926, vol. 79, pp. 389–390). An illustrated description is given of an oxy-illuminating gas torch for cutting metals. Tests show that illuminating gas is much more economical in machine cutting than either hydrogen or acetylene. Torches of the type described have been successfully used in the steel foundry for the removal of risers from castings.

The Purity of Oxygen for Metal Cutting (Engineering, May 21, 1926, vol. 121, pp. 591–592). A brief account of a paper on *Modern Developments in Oxygen Production from the Air*, by C. R. Houseman, read before the British Acetylene and Welding Association on Apr. 14, 1926. Experiments have proved that an increase in the purity of oxygen used for cutting from 98·5 to 99·0 per cent. had a marked effect on the quality of the work done.

Jet-Cutting Machines (Machinery, Aug. 12, 1926, vol. 28, pp. 541–544). The theory of oxygen-cutting and means of carrying it out are explained, and examples of its application to carriage and wagon building are given.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties and Tests of Cast Iron.—M. Rudeloff, *Shear Tests for Judging the Strength Properties of Cast Iron* (Die Giesserei, 1926, vol. 13; Aug. 14, pp. 577–584; Aug. 21, pp. 594–598). The shear tests previously described by the author (Stahl und Eisen, 1926, vol. 46, p. 97) have been further developed. Turned cast-iron test-pieces, with a collar 3·5 millimetres thick, were placed over a cylindrical die, and pressure was applied till the collar sheared off. This method the author calls "the hole-shear test." The collar is now provided with three radial slots, equidistant around the periphery, and a large number of tests have been made and the results compared with those of tensile, compression, torsion, punching, double shear and ball pressure tests. Curves show that all the results maintain a straight-line relationship, and by the application of a formula all the properties can be determined within a fair degree of accuracy from the hole-shear test.

G. K. Elliott, *A Shearing Test for Grey Cast Iron* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author discusses the use of the Frémont machine for the testing of cast iron, and describes its operation and construction. The results secured are compared with the results obtained by the usual transverse and tensile tests. Particulars are given of a modified shear-testing device, for use in connection with a universal testing machine, constructed to give double end shearing and to overcome some of the disadvantages of the Frémont machine. On account of the deficiences found in the machine used in the investigation, the author is not entirely in favour of the Frémont shearing test as a substitute for the transverse test for routine testing.

M. Rudeloff, *The Testing of Cast Iron at the Fourth Foundry Exhibition at Düsseldorf* (Die Giesserei, July 24, 1926, vol. 13, pp. 525–534). The article describes and illustrates a number of machines of various design for the testing of cast iron, including machines for bend tests, impact tests, tensile tests, hardness tests, shearing and compression tests, duration tests, and finally appliances for testing the machineability of iron and steel.

J. T. Mackenzie, *A Note on the Relations between the Proposed Standard Test Bar for Cast Iron and the Two Existing Standards* (Paper read before the American Society for Testing Materials, June 1926). A comparison is made of the results of tests carried out with the proposed A.F.A. test-bar. The author concludes that the proposed test-bar gives the best results for deflection and load and can be

advantageously substituted for the two existing standards. Cast iron tested transversely does not follow the conventional beam formulæ, which have been derived mathematically and apply only to homogeneous, isotropic, and elastic material. As such, when applied to cast iron, they are approximately true only for making corrections in the case of bars deviating only slightly from standard dimensions. The paper presents results to show the actual relationship and deviation from the elastic formulæ.

A Quick Testing Method for Cast Iron (Foundry Trade Journal, June 3, 1926, vol. 33, pp. 398–399). An English abstract of an article by P. Wolff (Stahl und Eisen, Apr. 29, 1926, vol. 46, pp. 560–564) describing a quick and reliable method for judging the quality of cast iron by examining the fracture of wedge-shaped specimens.

H. R. Pitt, *The Mechanical Testing of Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, July 29, 1926, vol. 34, pp. 93–97). The author discusses the principles of mechanical testing, and the precautions necessary in applying accepted methods of testing to cast iron. The co-relation of the tests and their value as applied to cast iron are also considered.

F. Roll, *Cooling Tests on Cast Iron Test-Pieces of Different Forms* (Giesserei-Zeitung, June 1, 1926, vol. 23, pp. 295–297). By means of cooling curves the differences in temperature which may occur in different parts of a casting during cooling are shown, and the effect of these differences on the structure and in producing internal stresses is discussed.

W. H. Rother and V. Mazurie, *The Strength of Cast Iron in Relation to its Thickness* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The authors give the results of a series of tests carried out in order to determine a factor which would be of help in calculating the true strength of grey iron castings of various thicknesses. Transverse tests were carried out on round and square bars, a 1-inch bar being used as a standard. Brinell and tensile tests were also carried out. It was found that iron with 2·15 per cent. silicon decreased on an average of about 6 per cent. in transverse strength for each $\frac{1}{2}$ inch increase in thickness between 1 and 3 inches. An iron with 1·70 per cent. silicon, and with a steel addition of 15 per cent., decreased 4 per cent. for each $\frac{1}{2}$ inch increase in thickness between 1 and 3 inches. An iron with 1·20 per cent. silicon, and with a steel addition of 25 per cent., had a decrease of 3·3 per cent. for each $\frac{1}{2}$ inch increase in thickness between 1 and 3 inches. The percentage decrease in transverse strength was found to be greater for square bars than for round bars. The percentage decrease in Brinell hardness with increasing thickness was found to be practically the same as the percentage decrease in transverse strength. It appears that the decrease in strength tends to follow the silicon content, as high silicon irons tend to show a greater decrease than low silicon irons containing steel. More research is necessary before any factors, which will be an aid in the calculation of the strength of iron castings, can be determined.

R. Hohage, *On Cast Iron* (Kruppsche Monatshefte, June 1926, vol. 7, pp. 101–109). The influence of elements and of the thickness of the casting upon the structure and the hardness of the metal is discussed, followed by a consideration of the effect of heat treatment on these characteristics.

L. Piedbœuf, *Comparative Study of the Results Obtained in the Improvement of the Quality of Cast Irons* (Revue Universelle des Mines, Oct. 1, 1926, vol. 12, pp. 2–11). The author reproduces Maurer's diagram for the classification of cast irons, and discusses the information which it gives. This diagram classifies the cast irons according to their carbon and silicon contents, and by its use the properties, structure, and behaviour of any cast iron may be forecasted, the phosphorus and sulphur being assumed to lie below certain limits. By the aid of this diagram the author explains the reasons for the good qualities possessed by certain "special" cast irons.

L. Piedbœuf, *Results Obtained in the Improvement of the Qualities of Cast Iron* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, June 24, 1926, vol. 33, pp. 496–499). A survey of the developments in the improvement of the strength of cast iron. High tensile cast irons generally have a structure that is almost entirely pearlitic, though sometimes high strengths are obtained with cast irons having a pearlitic and ferritic structure, provided the graphite is distributed in sufficiently fine lamellæ. Maurer's cast-iron diagram is reproduced, which subdivides the cast irons according to their texture in terms of carbon and silicon content. The diagram includes cylinder cast iron and Krupp special cast irons, and also the results of laboratory tests carried out by Wüst and Bardenheuer. The diagram has been supplemented by points showing a whole collection of special irons, pearlitic irons, and semi-steels. Portevin's diagram, which is also reproduced, shows within what limits the percentage of combined carbon may vary for pearlitic cast irons and semi-steels. The pearlitic structure alone is not sufficient to ensure high mechanical properties. There is another important point, namely, the diminution in the size of the graphite lamellæ. Numerous researches have been carried out in this direction, as a result of which the size of the lamellæ has been considerably reduced by treating the metal in an oil-fired or in an electric furnace. Tables are also included showing the mechanical properties of various special irons produced by different processes.

J. E. Hurst, *Some Further Notes on Pearlitic Cast Iron* (Foundry Trade Journal, Apr. 29, 1926, vol. 33, pp. 333–335). A consideration of the features governing the rate of cooling shows that whilst an increase in the mould temperature slows up the rate of cooling, it does not affect the rate of variation of the speed of cooling across the section of a mass of metal. The principal effect is to produce a larger grain-size in the resulting casting, and whilst uniformity of the pearlitic structure throughout the whole thickness of a casting may be obtained, a similar degree of variation in the properties from the outside to the

centre may be expected in hot-mould irons as in cold-mould irons. As a direct result of the larger grain-size, it would be expected that the properties would be inferior to those of the same material cast in a cold mould. It is highly probable that the explanation of any improved properties observed in Perlit iron are due more to the modified composition than to the use of a hot mould.

J. A. Smeeton, *Pearlitic Cast Iron* (Foundry Trade Journal, July 1, 1926, vol. 34, pp. 10–12). A criticism of the article by Hurst. It is claimed that castings are produced showing generally no variation in grain-size from the outside to the centre of the casting, or in extreme cases astonishingly little as compared with the ordinary process.

H. J. Young, *Grey Iron Castings for Special Needs* (Journal of the West of Scotland Iron and Steel Institute, Session 1925–26, vol. 33, Part 4, pp. 56–69). The author discusses the latest practice in the production of efficient grey iron castings, with special reference to the Perlit process. Particulars are given of comparative tests carried out by the author. The importance of homogeneity and grain-size is pointed out.

C. Gilles, *Production of High Strength Cast Iron* (Foundry Trade Journal, July 22, 1926, vol. 34, pp. 70–75). A slightly abridged English translation of a paper, together with discussion, on the production of pearlitic cast iron, which appeared in Giesserei-Zeitung, Apr. 15, 1926, vol. 23, pp. 203–212. (*See* this Journal, 1926, No. I. p. 557.)

A. E. M. Smith, *A Note on the Properties of "Perlit" Iron* (*Lanz Process*) (Foundry Trade Journal, July 1, 1926, vol. 34, pp. 13–16). The author discusses the characteristics and physical properties of Perlit iron, and gives the results of tests on this iron. Grain-size has little or no relation to the size of the pearlite lamellæ, and instead of slow cooling having the effect of reducing the impact value, the results of tests show that this value is greatly increased.

A. Hayes and H. U. Wakefield, *The Carbon Content of Pearlite in Iron-Carbon Alloys containing* 1 *per Cent. Silicon* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 214–232). The authors present a constitutional diagram for iron-carbon alloys of white iron composition, and have investigated the carbon concentration of the eutectoid. Alloys of varying silicon content and containing enough combined carbon to produce sufficient pearlite to cover from 30 to 60 per cent. of the cross-sectional area were prepared. The areas of ferrite and pearlite were carefully measured, the samples were then milled down and determinations for carbon and silicon were made. The carbon content of pearlite was calculated by dividing the combined carbon content by the fraction of the area covered by pearlite. The percentage of carbon in pearlite thus obtained was then plotted against the silicon content. Interpolation of the graph reproduced gives 0·669 per cent. for the carbon content of pearlite for an alloy containing 1 per cent. of silicon.

O. Smalley, *Heat and Scale Resisting Cast Irons* (Paper read before the American Foundrymen's Association, Sept.-Oct. 1926: Foundry Trade Journal, Oct. 7, 1926, vol. 34, pp. 303–305). The author deals with the subject under the following headings: (1) High duty castings, (2) chilling iron, (3) scale-resisting irons. Under the first heading the author deals with semi-steel and the influence of graphitisers, and discusses the advances made in foundry processes. In dealing with chilling irons the author discusses the annealing process for car wheels and gives the results of tests on wheels. A report of an investigation of scale-resisting irons is given, and the mechanism of the breaking down of ordinary white iron under heat oxidising conditions is discussed. The effect of elements on the heat-resisting properties is also dealt with.

R. D. Billinger, *Chilled Iron Resembles White Iron* (Iron Age, Aug. 5, 1926, vol. 118, pp. 345–346). The similarity between chilled grey iron and typical white iron is shown by means of photomicrographs. The effect of chilling and consequent hardening in thin grey iron castings, such as piston rings, is discussed.

K. Homma, *Studies of Chill Castings* (Kinzoku no Kenku, 1926, No. 2, pp. 96–117). The author has investigated the different factors affecting the hardness of chill castings.

J. T. Mackenzie, *The Influence of Phosphorus on Cast Iron* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926: Foundry, Sept. 1, 1926, vol. 54, pp. 681–684). The paper gives the analyses, bending curves, Brinell hardness, and results of drop tests of a large number of irons cast in $2 \times 1 \times 24$ inch bars. Phosphorus is shown to lower the strength and resilience, to increase the Brinell hardness, and to stiffen the bar slightly. Some data are given to show that in some cases phosphorus, by promoting fluidity and hence soundness of the casting, actually helps to make a stronger casting.

J. W. Bolton, *Phosphorus Affects Qualities of Grey Cast Iron* (Foundry, 1926, vol. 54; May 15, pp. 378–382; June 1, pp. 423–425). A summary of existing information on the mode of occurrence of phosphorus in cast iron and its influence on the physical properties.

J. E. Hurst, *The Condition and Influence of Sulphur in Cast Iron* (Foundry Trade Journal, 1926, vol. 34; Oct. 14, pp. 323–326; Oct. 21, pp. 355–356). A review of present-day knowledge concerning the influence and mode of existence of sulphur in cast iron as brought out by the results of different investigators.

J. Shaw, *Some Grey Iron Problems* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926: Foundry, Oct. 1, 1926, vol. 54, pp. 766–772). The author considers the influence of sulphur and manganese on the structure of cast iron containing ordinary amounts of the other usual elements. The influence of carbon and silicon, in conjunction with the other elements, on the structure, and the usefulness of various chill tests for judging roughly the ultimate

structure of molten metal, before casting, are also dealt with. Several theories are presented which have been advanced concerning the manganese-sulphur ratio, and the influence of furnace temperatures on the behaviour of sulphur and manganese, and the form of sulphur in cast iron, are dealt with. The author also discusses the various views accounting for the differences in loss of depth of chill between test-pieces and the results secured in castings. The concluding section of the paper deals with the effect of the ratio of carbon to silicon on the structure as judged by the chill test.

Alloy Iron Made Electrically (Iron Age, Sept. 16, 1926, vol. 118, pp. 764–765). A brief discussion of some of the applications and characteristics of cast iron containing nickel and chromium. At the plant of the Vulcan Mold and Iron Co., Latrobe, Pa., alloy cast iron is produced in an electric furnace. Castings are produced for die blocks, hammer dies, pistons, cylinder blocks, and ingot moulds. The same subject is also dealt with in *Electric Iron Has Close Grain* (Iron Trade Review, Sept. 23, 1926, vol. 79, pp. 783–784).

The Relations of the Mechanical Properties of Cast Iron to each other and to the Analysis (Foundry Trade Journal, Aug. 19, 1926, vol. 34, pp. 155–157). An English translation of Klingenstein's paper published in Die Giesserei, Feb. 27, 1926, vol. 13, pp. 169–173; *see* Journal of the Iron and Steel Institute, 1926, No. I. p. 619.

Concerning Cast-Iron (Machinery, Oct. 28, 1926, vol. 29, pp. 118–119). A few notes on the chemical and physical properties of cast-iron, and on the effects of various impurities.

A. N. Talbot and F. E. Richart, *A Study of the Relation between Properties of Cast-Iron Pipe Tested under Impact, Internal Pressure, and Flexure, and the Corresponding Properties Found in Several Kinds of Test Specimens taken therefrom* (Paper read before the American Society for Testing Materials, June 1926). The paper presents the results of tests on twenty-five lots of 6-inch cast pipe made by two sand-cast processes and two centrifugal processes. The following test specimens were used: rings, two forms of tension specimens, and strips for cross bending tests. Comparisons are made of the strengths of the various test specimens with the bursting strengths of the pipe and with their flexure strengths. It was found that the strength of the test strip was an index of the strength properties of the pipe. A study was also made of the modulus of elasticity found in the test strip and of that in the pipe itself. The impact tests gave interesting information on the resistance of the metal to blows.

E. Piwowarsky, *Observations on the Behaviour of Cast Iron in Heated Steam* (Die Giesserei, July 3, 1926, vol. 13, pp. 481–484). A series of experiments was made to determine the effect on cast iron of an exposure to the action of steam at high temperatures. High pressure steam was not available, and steam at atmospheric pressure from distilled water was used by drawing it by suction through a porcelain tube furnace, in which bars of cast iron were placed. Five types of cast

iron were synthetically manufactured for the purpose of the experiments, and the melts were of the following composition :

Melt.	Total Carbon.	Silicon.	Manganese.	Sulphur.	Phosphorus.	Chromium.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	3·55	2·13	0·50	Under 0·03	trace	...
2	3·04	1·08	0·43	,,	,,	...
3	2·89	0·97	0·46	,,	0·63	...
4	2·98	1·14	0·47	0·12	trace	...
5	3·42	1·00	0·48	Under 0·03	,,	1·12

The best Swedish pig-iron and Krupp soft iron formed the basis of these melts, the other elements being added as required. Bars of these materials were then heated in the furnace for 75 hours at three ranges of temperature, namely, 300°, 350°, and 450°, steam at atmospheric pressure being drawn through the whole time. At the end of the heats the bars were weighed, and all were found to have increased in weight, due to formation of scale. The relative increase at 300° was greatest in the case of melt (1), namely, 0·41 per cent., and lowest for melt (4), with 0·23 per cent.; the corresponding weight increases after heating at 450° were 2·80 for melt (1) and 1·72 per cent. for melt (5), or about seven times as much as when heated at 300°. The increases in volume of the bars heated at 450° were for melt (1) 10·2, for melt (2) 4·4, for melt (3) 4·2, for melt (4) 6·6, and for melt (5) 5·4 per cent. The cores of the bars were then examined to see to what depth oxidation had penetrated. Of the bars heated at 350° only those higher in silicon showed oxidation in the core zone. Of the bars heated at 450° the higher silicon bars and the high sulphur bar were strongly oxidised in the core zones, while the low silicon and the chromium bars were practically free from oxidation, especially the latter, on account of its denser structure. The dissociation of carbides is much more marked in bars heated under steam than when in contact with air, and under steam the loss of total carbon amounts to 10 to 15 per cent. At 450° under steam sulphur promotes the corrosion of cast-iron.

The Influence of Hot Steam on Cast Iron (Foundry Trade Journal, Aug. 12, 1926, vol. 34, pp. 139–140). An English translation of Piwowarsky's experiments reported above.

The Structure of Cast Iron (Metallurgist, May 28, 1926, p. 74). A comparison of the ideas and experiments put forward by Piwowarsky concerning the superheating of cast-iron (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 617) and those of Hanemann, expounded in a lecture on March 3, 1926, before the Berlin branch of the Betriebsverein deutscher Ingenieure.

R. Higgins, *The Dilatation of Cast-Irons during repeated Heating and Cooling between 15° C. and 600° C.* (Iron and Steel Institute : Carnegie

Scholarship Memoirs, 1926, vol. 15, pp. 217–232). Dilatation curves were registered for two series of cast-irons containing approximately 1·5 per cent. silicon. In the first series the phosphorus was low and the manganese varied, while in the second series the reverse was the case. A small partial oxidation of the iron and graphite was shown to occur, the number of heatings being twenty-one, and the maximum temperature 600° C., at which temperature the specimens were soaked for three hours. In the manganese series the growth was due to oxidation and graphitisation; an increase in the manganese contents stabilised the iron against changes in the coefficient of expansion. In the phosphorus series increase of the phosphorus delayed the growth; the phosphorus protected the iron from oxidation and also increased the uniformity of the coefficient of expansion. Grey irons showed no growth after a certain number of heats, but their coefficient of expansion could be very erratic.

C. E. Pearson, *The Growth of Commercial Grey Cast-Iron* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 281–317). Carpenter and Rugan's conclusion that growth is primarily caused by oxidation of silicon and iron, and is greater the higher the silicon content, is confirmed. The rate at which the iron cools after casting influences the susceptibility to growth; there is a critical size of graphite particle which is most favourable to growth. Iron heated continuously under oxidising conditions attains a maximum growth for any one heating in a few hours, the length of time depending on the nature of the oxidising gases. Iron cast by the Lanz process may have very little silicon and will show little growth. In the absence of oxidising influences the growth will be quite inconsiderable, the small amounts found being attributable to occluded gases in the iron, and the decomposition of cementite when present. Repeated heating *in vacuo* leads to some growth, due apparently to occluded gases.

E. Piwowarsky, *The Growth and Shrinkage of Cast-Iron and of High Quality Grey Castings* (Giesserei-Zeitung, 1926, vol. 23; July 15, pp. 379–385; Aug. 1, pp. 414–421). The influence of silicon, of the condition of the carbon and graphite, and of the structure of the metal in promoting or preventing growth, has been fully studied, and the results are shown by means of diagrams and micrographs.

E. Piwowarsky, *The Effect of Growth and Shrinkage on the Properties of High Quality Grey Cast-Iron* (Paper read before the Verein deutscher Giessereifachleute: Foundry Trade Journal, Aug. 26, 1926, vol. 34, pp. 180–183).

J. E. Hurst, *A Note on "Growth" in Cast-Iron* (Foundry Trade Journal, Aug. 12, 1926, vol. 34, pp. 137–138). The author points out the analogy that exists between the spalling phenomenon in refractory bricks and the growth phenomenon in cast-iron. The spalling phenomenon is considered, and Norton's formula is applied to the study of the growth of cast-iron.

R. R. Kennedy and G. J. Oswald, *The Effects of Various Alloys on the Growth of Grey Cast Iron under Repeated Heatings* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). In an attempt to develop a grey iron which would have a slow rate of growth under repeated heatings, manganese, phosphorus, nickel, and chromium were added to iron in the ladle. Iron was also deoxidised by an addition of titanium. Bars were packed in a steel pot with cast-iron borings and the lid was luted with fireclay. The pot was heated in a gas-fired muffle furnace to a temperature of 1550° F., the duration of each heat being three hours. The bars were unpacked and measured after various heatings. The results show that the addition of phosphorus and deoxidation with titanium had the greatest effect in retarding growth. As an explanation the authors suggest the following : (1) The steadite in high phosphorus iron forms an envelope around the grains of iron. This envelope has the effect of slowing down the rate of penetration of the gases which cause growth. (2) If growth be due, as is commonly held, to the action of oxygen or other gases, in a deoxidised iron the growth must all be caused by gases which penetrate from the exterior of the casting, and not, in part, by gases already in the iron. For that reason the rate of growth of a deoxidised iron would be slower than that of an iron which was not deoxidised.

J. E. Hurst, *The Total Carbon Contents of Cast-Iron* (Engineering, May 21, 1926, vol. 121, pp. 583–584). The difference between steel, with its high strength and ductility, and cast-iron, with its low strength and absence of ductility, is principally a question of total carbon content. It would be expected, therefore, that a reduction of the amount of total carbon in a cast-iron would be accompanied by some improvement in its mechanical properties. The ternary constitutional diagram of the iron-silicon-carbon alloys is studied in order to obtain a clearer conception of the constitutional changes involved in the lowering of the total carbon content. The differences between low total carbon content alloys and normal cast-irons of eutectic composition are summarised as follows : (i) Solidification takes place over a range of temperature ; (ii) solidification commences at a higher temperature ; (iii) the austenite solid solution is deposited first ; (iv) the amount of solid solution in the final alloy is increased. The manner and character of the graphite formation is likewise influenced, resulting also in better mechanical properties.

The Influence of Prolonged Heating on the Formation of Combined Carbon in Cast Iron (Foundry Trade Journal, June 10, 1926, vol. 33, p. 411). An English abstract of the results obtained by O. Wedemeyer, whose original paper appeared in Stahl und Eisen, Apr. 29, 1926, vol. 46, pp. 557–560. (*See* this Journal, 1926, No. I. p. 617.)

Kühnel, *Results of Examinations of Firebars* (Die Giesserei, Oct. 23, 1926, vol. 13, pp. 809–815). Previous literature on firebars is reviewed, and the results of new investigations are reported, showing changes in the structure and in sulphur and phosphorus after prolonged use.

Some Results of Tests on Firebars (Foundry Trade Journal, Sept. 2, 1926, vol. 34, p. 199). An English abstract of a paper read before the Verein deutscher Eisengiessereien Giessereiverband.

H. M. Ramp, *Why is Grey Iron Porous* (Foundry, May 1, 1926, vol. 54, pp. 354–355). The author presents his conclusions on the porosity of grey cast iron, based on many years experience in grey iron foundry practice.

J. H. Partridge, *Cast Iron for Electrical Machines* (Paper read before the Institute of British Foundrymen: Foundry Trade Journal, 1926, vol. 33; June 17, pp. 459–462; vol. 34, July 8, pp. 37–41; July 22, pp. 67–69; *see also* Journal of the Iron and Steel Institute, 1925, No. II. pp. 191–224).

Dissect Properties of Chinese Casting (Foundry, May 1, 1926, vol. 54, pp. 335, 358). The results are presented of a chemical and metallographical examination of cast iron from cooking pots produced by Chinese native methods.

New Cast Iron (Iron Age, May 27, 1926, vol. 117, pp. 1559–1560). Brief particulars are given of a new cast iron known as "Meehanite." It has an average ultimate tensile strength of 50,000 lbs. per square inch. The yield point is within 2 per cent. of the ultimate strength. Transverse and torsional strengths are likewise high. The average Brinell hardness is 258 and the material is readily machined. The physical strength is attributed to its dense matrix of uniformly distributed nodules of graphitic carbon. It is highly resistant to acids. No particulars are given of its manufacture, although it is said to be analogous to that used for making malleable cast iron. The chief feature in its production is the use of calcium silicide.

R. D. Allen, *The Embrittlement of Black-Heart Malleable Iron Resulting from Heating Overstrained Material* (Transactions of the American Society for Steel Treating, Oct. 1926, vol. 10, pp. 630–637). Test-bars of black-heart malleable iron were subjected to hammering, and were afterwards heated to a low temperature. They revealed a white steely fracture accompanied by extreme brittleness. It was found that by quenching the iron in this brittle state from 1200° F. in water the original black fracture returned accompanied by considerable toughness. It was also found that if malleable castings were previously subjected to the quenching the steely fracture could not be produced, and the toughness would not be changed when the castings were hammered and then heated to low temperatures.

C. Kluijtmans, "*Shrink*" *in Black-Heart Malleable* (Foundry Trade Journal, Aug. 5, 1926, vol. 34, pp. 123–125). Two types of shrink are recognised (1) those filled up with iron and showing in the centre of the section a granular area surrounded, in white iron, by large crystals, and (2) those showing a hole which as a rule is surrounded by a rim of granular iron. Both types are illustrated and their formation is discussed.

C. Kluijtmans, *Carbon in Black-Heart Malleable* (Foundry Trade

Journal, Aug. 12, 1926, vol. 34, pp. 133–135). For black-heart malleable the carbon content should be between 2·20 to 2·60 per cent. The author carried out tests on bars of different thicknesses and of the following composition: Silicon 0·78 to 0·82, carbon 2·52 to 2·57, and manganese 0·26 per cent. They were poured from the same heat, and the rate of cooling varied from two hours for ½-inch bars to fifteen hours for 2-inch square bars. They were then broken and the fractures examined; they showed that the slower the cooling the larger the masses of cementite formed. After annealing it was found that the whole of the cementite had been decomposed into graphite and ferrite in the small bars, whilst in the large bars a large percentage of cementite had not been decomposed. As a result of the tests it was concluded that, for similar annealing conditions, the larger the initial masses of cementite the larger the resultant graphite would be.

K. v. Kerpely, *Present State of Knowledge concerning the Formation and Forms of Graphite in Cast Iron* (Giesserei Zeitung, Aug. 15, 1926, vol. 23, pp. 435–446). A review of recent research work on the subject.

H. A. Schwartz, *Graphitisation at Constant Temperature* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 883–906; vol. 10, July, pp. 53–66). The paper consists of a mathematical analysis of the data of graphitisation at constant temperature, and outlines a means for the laboratory determination of the graphitising rate, as a physical constant of any given hard iron. As far as the author is aware, this method is new, and constitutes the only practical application of the theoretical principles considered. It is demonstrated that the rate of graphitisation is determined by the rate at which carbon can migrate in iron. The progress of graphite formation with time is shown to be an expression of the changing migratory distances and concentration gradients produced by the reaction. The procedure by which the mathematical characteristics of the observed graphitisation curve are used to determine the character of the physico-chemical processes occurring is unusual, and possesses interest for the theoretical metallurgist. Reference is made to the range through which the graphitising rate varies in commercial material, and the effect of silicon on this constant is discussed.

H. A. Schwartz and C. M. Guiler, *Chemical Elements Inhibiting Graphitisation* (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 639–645). The authors discuss the chemical elements which inhibit graphitisation of iron. It is shown that of the ninety-two possible elements, only antimony, boron, chromium, cerium, lanthanum (and rare earths), selenium, tellurium and tin, interfere with graphitisation when present in small amount in iron of normal composition. Of these, only chromium and tin have been detected in commercial materials so far. The rôle of oxygen in this connection is not yet demonstrated, although no evidence yet exists that it inhibits graphitisation.

T. Kikuta, *On the Malleable Cast Iron and the Mechanism of its Graphitisation* (Science Reports of the Tôhoku Imperial University, Sendai, 1926, vol. 15, pp. 115–155). The author presents the results of a dilatometric investigation of the graphitisation of white cast iron. Dilatation curves and photomicrographs are included in the paper. The first stage is the graphitisation of free cementite taking place above the A1 point. The second stage is the graphitisation of eutectoid cementite which takes place just below the A1 point. Both stages are greatly affected by the annealing temperature, and the time required to complete them decreases logarithmically with the rise of temperature. An intimate relationship exists between the thickness of the casting and the size of the free cementite, and the graphitisation of the free cementite will become more difficult as its size becomes larger or the casting thicker. An increase in tapping temperature of the melt also hinders graphitisation. An increase of silicon content decreases logarithmically the time required to complete both stages of graphitisation. Carbon has a similar effect on the second stage only. Manganese hinders graphitisation, especially the second stage, and the content of this element should be limited to below 0·5 per cent. Sulphur acts in a similar manner to manganese, and should be limited to below 0·06 per cent. Phosphorus assists the first stage but hinders the second, and should not be over 0·3 per cent. Some results of rapid heat treatments of white iron are included. It was possible to obtain black-heart malleable iron from white iron containing more than 2·5 per cent. of carbon and 1 per cent. of silicon in fifty-four hours.

E. Touceda, *Resistance of Malleable Iron to Repeated Impact Stresses and Comparison of Strength of Machined and Unmachined Malleable Castings* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). Malleable iron and cast steel castings were subjected to vertical static and drop tests, and the results are recorded. The composition of the material was as follows :

	Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
Cast steel . . .	0·24	0·49	0·25	0·027	0·040
Malleable iron . .	2·23	0·32	0·90	0·030	0·035

A comparison of the physical properties as determined from specimens cut from the castings, with the properties determined from test-bars, shows the properties of the malleable iron to be more consistent than obtains in the case of the cast steel. In general, it can be stated that the physical properties of malleable castings as determined by testing the castings can be depended upon to show from 90 to 95 per cent. of the figures as obtained from regular tensile specimens. A comparison of the deflection curves for the static tests shows that the deflection is about the same for both materials. In the drop tests the malleable iron showed slightly less deformation than the cast steel. The tests on the machined and unmachined bars clearly indicate that

the assumption that when the skin of a malleable iron casting is removed the latter has lost its strength in large part is incorrect.

H. Pinsl, *Investigation of Malleable Cast Tensile Test-Bars of Different Sections* (Die Giesserei, May 15, 1926, vol. 13, pp. 365-372). Describes an investigation on tensile test-bars of malleable cast iron. Round bars, flat bars, cruciform bars, and H bars were broken in a testing machine, and an examination was made of the fractured surfaces and of polished and etched sections, with a view to determining the distribution of the temper carbon and the relation between the microstructure and the tensile strength.

O. Quadrat and J. Koritta, *A Study of Malleable Cast Iron* (Paper read before the American Foundrymen's Association, Sept.-Oct. 1926: Foundry Trade Journal, Oct. 7, 1926, vol. 34, p. 306). The paper gives the results of an investigation carried out to study the influence of temper carbon and the effect of low and high temperatures upon the physical properties of the grey heart of malleable castings. The tensile strength of the ferritic material containing the grains of the temper carbon was also determined.

E. R. Taylor, *The Influence of Manganese on the Properties of Whiteheart Malleable Cast-Iron* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 381–406). As a result of his experiments the author concludes that the best all-round mechanical tests are obtained with whiteheart malleable cast-iron when the ratio of the manganese to sulphur is as 1·7 to 1, whatever the sulphur may be. Excellent bend tests may be obtained with less manganese than is represented by that ratio, but the elongation values fall off rapidly. Better results are obtained with low-sulphur than with high-sulphur pig-iron when the manganese to sulphur ratio is 1·7 to 1 in both cases. During the annealing of white-iron castings, sulphur, if present as ferrous sulphide, is always eliminated more or less; but when the manganese to sulphur ratio equals or exceeds 1·7 to 1, there is a gain in sulphur during annealing owing to absorption from the ore mixture. High manganese confers strength on whiteheart malleable, but without ductility. Castings of such material anneal to a finely divided pearlite instead of ferrite.

Properties and Tests of Steel.—C. M. Campbell, *Some Physical Properties and Compositions of Cast Converter Steel* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The author presents the results of tensile tests of several heats of cast carbon steels made by the converter process. Attention is drawn to the high ductility obtained from test-bars in the "as cast" and annealed conditions, also to the uniformity of composition of various kinds of carbon steels. The low limits within which it is possible to hold sulphur in converter steel are discussed.

H. J. French, *Methods of Test in Relation to Flow in Steels at Various Temperatures* (Paper read before the American Society for Testing

Materials, June 1926). The author has investigated the flow in a low-carbon structural steel, a high-chromium steel, and a low-tungsten high-vanadium high-speed steel, when subjected to fixed tension loads at temperatures between 70° and 1350° F. (20° and 730° C.). The loads and temperatures were maintained for varying periods up to five months depending upon test conditions, and the results are correlated with factors which may be determined in the customary short-time tension tests. It was found that the proportional limit, determined in the short-time tension test by an accurate extensometer, which is briefly described, approximated to the loads permitting long life with freedom from deformation in the flow tests at corresponding temperatures. Within the temperature range in which strain hardening is observed this is lower than the "limiting creep stress" referred to by other investigators; at higher temperatures it is equivalent to the latter. The paper also records the adaptation to high-temperature tension tests of the Tuckerman-Martens optical extensometer, and a brief discussion is given of the dependence of results in both flow tests and tension tests upon the accuracy of the test equipment used.

G. Sachs, *Analysis of the Tensile Test* (Mitteilungen aus dem Materialprüfungsamt Berlin-Dahlem, 1926, Special Series, No. II., pp. 114–123). The point of maximum load is calculated for a constant stress-area curve. It is postulated that the points of attainment of maximum load, the beginning of local contraction, and the cessation of uniform elongation all coincide. The effect of a constant and of an irregular course of the stress-area curve may reveal itself by the repetition of the contraction at several points. Due to the contraction and to the head of the bar a truly uniform elongation occurs only with very long bars.

R. L. Templin, *Effects of Size and Shape of Test Specimen on the Tensile Properties of Sheet Metals* (Paper read before the American Society for Testing Materials, June 1926). The paper covers a series of tensile tests on three types of sheet metals—namely, (1) material having a comparatively high tensile strength and a low elongation; (2) material having comparatively low tensile strength and a high elongation; (3) material having both a high-tensile strength and a high elongation. The major portion of the paper deals with the effect of variations in the width and length of the reduced section of the test specimen. The second portion of the paper is concerned with the effects of radius of fillets and end width on the mechanical properties of the material used. The results indicate that the tensile strength and yield point of the material are affected in only a few extreme cases by the size and shape of the test specimen used. The elongation is affected quite seriously by the total cross-sectional area of the test specimen rather than by the form of the test specimen, except in so far as the form of the test specimen may cause fracture to occur outside of the middle third of the reduced specimen. Heretofore, the value of the ratio of width to thickness of the reduced section has been con-

sidered one of the major factors, affecting the elongation. A few supplementary tests are included for the purpose of verifying the relationship found to exist between total cross-sectional area and elongation.

P. Ludwik, *Estimation of the Resistance to Breaking from the Uniform Extension* (Zeitschrift für Metallkunde, Sept. 1926, vol. 18, pp. 269–272). The author distinguishes between *Reissfestigkeit* (resistance to breaking) and *Zugfestigkeit* (tensile strength). The latter term corresponds to the usual English meaning, but the former, which he also calls the "effective tensile strength," is expressed by the ratio of the breaking load to the diminished area of the test-piece at the moment of fracture. The two values of course differ the more, the more ductile the metal happens to be. A method of estimating fairly closely the resistance to breaking is described, in which it is not necessary to reduce the load towards the end of the experiment as in the old way, or to measure the load at the moment of breaking. The only measurement additional to those ordinarily taken during a tensile test is the "uniform extension"—that is, the extension of the cylindrical unrestricted portion of the test-piece. A table of results is given comparing some experimental results with calculated values.

The Yield Point and Cold and Hot Brittleness of Steel (Metallurgist, June 25, 1926, pp. 85–87). An English abstract of an article by P. Ludwik in Zeitschrift des Vereins Deutscher Ingenieure, Mar. 1926, vol. 70, p. 379. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 628.)

H. P. Hollnagel, *Stress-Strain Curves and Physical Properties of Metal, with Particular Reference to Hardness* (Transactions of the American Society for Steel Treating, July 1926, vol. 10, pp. 87–108). An interpretation of the stress-strain curve is given in terms of the forces of restitution of the atoms, of slip of an atomic nature, and of mass. Restitution depends on interfering material which is probably amorphous. The various physical properties are discussed in terms of these factors as associated with the stress-strain curve. Hardness is defined as an average property of all other physical properties which are expressible in terms of the stress-strain curve, and a means is suggested for correlating the various hardness numbers. It is furthermore pointed out that hardness from the viewpoint of an average property may be defined as the work per unit volume per unit strain, and that this definition has the physical dimensions of pressure.

K. Honda and T. Tanaka, *On the Moduli of Elasticity and Rigidity, and their Change caused by Magnetisation, in Different Kinds of Steels* (Science Reports of the Tôhoku Imperial University, Sendai, 1926, vol. 15, pp. 1–37). Carbon-nickel and cobalt steels were used in the investigation. In the case of carbon steels, the moduli of elasticity and rigidity were measured both in the annealed and quenched states. Quenching causes a decrease in the moduli, and a similar effect occurs with increase in carbon content. They are increased by magnetisa-

tion in all fields. In the case of cobalt-iron alloys the elastic constants are also increased by magnetisation, except in weak fields in the case of alloys containing between 35 to 55 per cent. of cobalt, in which a small decrease is observable. In the case of nickel steels, the elastic constants are increased by magnetisation for all fields, with the exception of the irreversible nickel steels, in which a small decrease of these constants is observable. Generally speaking, the change in the modulus of rigidity is about three times greater than that in the modulus of elasticity in the steels investigated.

K. Honda, *A Comparison of Static and Dynamic Tensile and Notched-Bar Tests* (Paper read before the Institute of Metals, Sept. 1926).

J. W. Percy, *Impact Tests of Nickel-Chromium Steels* (Michigan Engineering Experiment Station, 1925, Bulletin No. 2).

G. A. Hankins, D. Hanson, and Miss G. W. Ford, *The Mechanical Properties of Four Heat-Treated Spring Steels* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 265).

J. K. Wood, *The Specification and Control of Mechanical Springs* (Paper presented to the American Society of Mechanical Engineers, May 3–6, 1926: Mechanical Engineering, Aug. 1926, vol. 48, pp. 808–814). The paper deals with specifications for the manufacture of springs and spring materials. A list of available specifications for heavy springs and a table showing their features are given. A suggestion for drawing up specifications where none are available for small springs is discussed, and the author illustrates his method by an example. He introduces a "load-deflection sector" in place of a load-deflection curve, and uses it in the example mentioned.

A. Lundgren, *The Testing of Hardened Steel* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 225).

K. Tamaru, *On the Mechanical Properties of Titanium Steel* (Science Reports of the Tôhoku Imperial University, Sendai, 1926, vol. 15, pp. 73–80). Titanium steel melted in hydrogen has a much higher tensile strength than carbon steels. The yield point is considerably higher than that of carbon steels, and slightly decreases with an increase of carbon content. The elongation of titanium steels is much less than that of carbon steel, and the contraction of area much higher.

J. R. Dawson, *Strength of Welded Joints* (Paper read before the American Society for Testing Materials, June 1926). The author presents the results of tests on oxy-acetylene welds on strips of $\frac{3}{8}$-inch steel plate, using a welding-rod containing 0·20 carbon, 0·80 manganese, and 0·60 per cent. silicon. In the majority of cases the fracture of the test-piece was outside the weld which showed strengths equal or superior to the original metal. A summary and analysis are given of the results on bars broken in tension. The macrostructure and microstructure of the welded specimens and the nature of the fractures are illustrated.

H. H. Moss, *Tests on Gas-Welded Roof Trusses* (Iron Age, Aug. 26, 1926, vol. 118, pp. 544–546). The results are given of an investigation

of the strength of oxy-acetylene welded roof trusses. An "insert plate joint" was developed in an attempt to place web metal concentrically around centre lines in a theoretical diagram, and by adding long steel rectangles on either side of this web material, to obtain sufficient area and rigidness for a practical structure. It is apparent that the insert plate joint is a step toward the solution of the problem of joining structural steel by oxy-acetylene welding. The results of the tests show a rigidity in favour of welding of approximately 15 per cent.

N. S. Otey, *How Metal Tubing Should be Tested* (Iron Age, Aug. 19, 1926, vol. 118, pp. 477–480). The author gives the results of some recent tensile tests on tubes carried out at the Naval Aircraft Factory, Philadelphia. The tests demonstrate that the percentage elongation over a given gauge length of tube, tested in full section, is very different from that of a flat specimen prepared from the same tube. The results show clearly that for a given material the most influential factor governing the elongation values is the diameter of the tube.

H. W. Swift, *The Elasticity of Wires and Cables* (Engineering, 1926, vol. 121; Apr. 30, pp. 547, 548; May 28, pp. 615–617). Various methods of determining the modulus have been proposed at various times; a critical comparison of some of them is made, and tests made to determine their accuracy are described. The types of test are divided into (i) those using extensometers, (ii) those employing verniers, and (iii) those dependent on the sag in a horizontal span, and their various merits and demerits are discussed; the third method is considered in some detail. The checking tests carried out showed that each method could give reliable results if used with reasonable care. Measurements at low tension do not yield useful results in either case, and the method of oscillations in span is not suitable when the stress-strain relation of an inelastic material is required.

W. Voigtlander, *Care Prolongs Wire Rope Life* (Iron Trade Review, Aug. 26, 1926, vol. 79, pp. 500–502). The author discusses a number of hints for the maintenance, handling, and splicing of wire ropes.

The Effect of Plastic Straining and Periodical Heat Treatment upon the Mechanical Properties of Wrought Iron Chains (National Physical Laboratory, Annual Report for 1925, pp. 171–173). An outline is given of the work which is being carried out at the National Physical Laboratory in connection with the heat-treatment of chains. The main object of the research is to study the effects of, first, low-temperature annealing (650° to 760° C.), and, secondly, normalising, upon the mechanical properties of chains which have been subjected to varying degrees of plastic strain. Particulars are given of the work performed to date, the scheme of tests drawn up, and the conclusions arrived at from the test results.

E. Siebel, *Behaviour of Steam Boiler Ends under Stress* (Stahl und Eisen, Sept. 2, 1926, vol. 46, pp. 1181–1191). A study of the distribution of stresses in boiler ends of different form, by means of an examina-

tion of the lines of flow on the surfaces and Fry's etching figures on the sections of the plates. From the results conclusions are drawn as to the best form to give to the dished boiler ends and to the manhole covers.

E. Siebel and F. Körber, *Tests to Determine the Stress and Deformations of Domed Boiler Bottoms with and without Manholes, due to Internal Pressure* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1926, vol. 8, No. 1, 51 pp.). A second report on the subject. Further experiments were carried out along lines similar to those described in the first report (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 640). In an appendix boiler bottoms with holes drilled in them are dealt with, and compared with unbored ends. The most suitable form for the holes is suggested.

E. Siebel and A. Pomp, *The Connection between the Strain Distribution and the Formation of Flow-Lines in Boiler Ends with and without Manholes, resulting from Internal Pressure* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1926, vol. 8, No. 3, 15 pp.). When a body is stressed beyond its yield point, the traces of the planes of movement will appear on the surface and in sections of the body; the shape of these traces is dependent on the stresses existing at the particular place. There is an indirect relationship between the distribution of stress after plastic deformation has set in and that during purely elastic change of shape. An investigation of this relationship was carried out on a series of boiler ends in which the stress distribution was known.

S. W. Miller, *The Design of Dished Heads of Pressure Vessels* (Mechanical Engineering, Aug. 1926, vol. 48, pp. 845, 846). The article describes tests carried out on a cylindrical pressure tank having dished ends. As a sequel to the results obtained the author points out the need for a careful and complete study of the stresses round openings in all such vessels, and suggests the manner in which such tests should be made.

E. Höhn, *Displacements and Permanent Stresses in Locally Heated Plates* (Archiv für Wärmewirtschaft, 1926, vol. 7, pp. 172–174). Tests on plates show that on local heating the heated metal particles tend to migrate, and that as the migration is hindered by surrounding cold parts, internal permanent stresses are set up when the plate is cooled.

S. P. Vologdine, *Study of the Stresses in Soft Iron by the Method of Tempering* (Journal of the Russian Metallurgical Society, 1925, Part 1, p. 67).

H. Hoff and G. Sobbe, *Plastic Deformation* (Maschinenbau, Feb. 4, 1926, vol. 5, pp. 109–112). The property of plasticity is discussed, and a brief summary is given of the present theories of the processes involved in the upsetting of plastic bodies.

P. L. Irwin, *Fatigue of Metals by Direct Stress* (Paper read before the American Society for Testing Materials, June 1926). The paper deals with metals whose proportional limit in tension is below the

endurance limit. The paper contains data of chemical analyses, heat treatment, tension tests, endurance limits under flexural stress, and endurance limits under axial stress for certain non-ferrous metals and stainless iron.

F. F. McIntosh, *Effect of Phosphorus on the Endurance Limit of Low-Carbon Steels* (Mining and Metallurgy, Aug. 1926, pp. 332–333). A survey of the work of different investigators on the effect of phosphorus on steel, from which the author concludes that phosphorus should be considered as an alloying element which is capable of conveying valuable properties to steels when used within certain limits of composition.

F. F. McIntosh and W. L. Cockrell, *The Effect of Phosphorus on the Resistance of Low-Carbon Steel to Repeated Alternating Stresses* (Carnegie Institute of Technology, 1925, Mining and Metallurgical Investigations, Bulletin 25). The report opens with a review of previous investigations on the fatigue of steel and the influence of phosphorus in ferrous alloys. The steels used in the present investigation were of basic open-hearth manufacture and averaged 0·10 per cent. of carbon. The phosphorus additions were made in the ladle. The results of the investigation are therefore intended to apply to steels where the phosphorus content is added rather than residual, owing to the strong evidence for the existence of a difference in the effect of added and residual phosphorus. The fatigue testing machines used in the investigation are described and the results of the tests are discussed. It is concluded that the addition of from 0·010 to 0·125 per cent. of phosphorus to low-carbon basic open-hearth steel increases the endurance of the material against repeated alternating stresses, increases its hardness, ultimate strength and elastic limit, and has no particularly bad effect on the resistance to shock or vibratory strain. It also increases the resistance to corrosion and abrasion and has no well-defined effect on ductility. A bibliography of literature on fatigue and effects of phosphorus on iron and steel is appended to the report.

H. F. Moore and T. M. Jasper, *The Fatigue of Metals* (Engineering Foundation, New York, Report for 1926, Publication No. 11, pp. 33–105). The present report has been abridged and partially rewritten from Bulletin 152 of the Engineering Experiment Station of the University of Illinois (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 627).

K. Heindlhofer and H. Sjövall, *Endurance-Test Data and their Interpretation* (Transactions of the American Society of Mechanical Engineers, 1923, vol. 45, pp. 141–150). The average life determined by repeated endurance tests is a valuable characteristic of comparison as it shows the general magnitude of life, but taken alone it is insufficient to define durability. It must be amended by a second quantity expressing the dispersion or range of variation of the individual lives, which is an indication of reliability. Since the number of available tests is limited, its average is approximate, the precision depending on the

number of tests. The authors' object was to develop methods for computing the probable error in the estimated average life of an object, depending on the number of repeated tests. This error is a measure of the reliability of the average. The results are presented in the form of a diagram which shows this probable error at a glance. It is suggested that endurance curves may be used to determine whether an elimination test will be advantageous in the case of products made in quantity.

G. Welter, *Resistance to Repeated Shock and the Dynamic Limit of Elasticity* (Zeitschrift des Vereines Deutscher Ingenieure, 1926, vol. 70; May 15, pp. 649–655; June 5, pp. 772–776). In view of the utility of the repeated stress test, the author has devised a speedier method of applying the test. A light pendulum hammer is employed, the maximum impact effect of which does not exceed 40 centimetre-kilogrammes. The test-bar is held in the machine and is turned automatically after each blow through 180°, the force of impact gradually being increased by amounts equal to two divisions on the scale, until the first sign of permanent deformation is detected, showing that the dynamic limit of elasticity is reached. Thereafter increments equal to five divisions of the scale are imparted to the force of impact. The time taken for the performance of a single test need not exceed five minutes. A direct relation is found to exist between the dynamic limit of elasticity and the ultimate resistance to repeated impact.

Fatigue under Repeated Impact Stresses and its Relation to the Dynamic Elastic Limit (Metallurgist, July 30, 1926, pp. 108–110). An English abstract of the above paper by Welter.

G. Welter, *Static Endurance of Metals and Alloys* (Zeitschrift für Metallkunde, 1926, vol. 18; Mar., pp. 75–80; Apr., pp. 117–120). The author has carried out experiments in which tensile test-pieces were kept under various static loads for long periods. Among the many metals and alloys investigated were two steels: one contained 0·3 per cent. carbon and was cold-drawn after rolling, and the other, with 0·15 per cent. carbon, was tested in the "as rolled" condition. The former steel showed no signs of failure at a stress not far below the normal ultimate stress after six months' exposure; the latter also did not fail, but the stress employed did not exceed very much the ordinary yield stress. The tests were made in the open air, in order to approximate to service conditions.

Static Endurance Tests (Metallurgist, Apr. 30, 1926, pp. 58–60). An English abstract of the above paper by G. Welter.

R. R. Moore, *Effect of Grooves, Threads, and Corrosion upon the Fatigue of Metals* (Paper read before the American Society for Testing Materials, June 1926). The paper gives the results of tests showing the effect of various shapes and sizes of notches upon the endurance limit of a heat-treated chrome-vanadium steel and an aluminium-copper alloy. Static tension test results are compared with dynamic endurance test results to show the difference between the relative effects of the notches under static and dynamic stresses.

Y. Fujii, *Fatigue of Steel and its Recovery* (Kyoto College of Engineering, Mar. 1926, Memoir No. 4, pp. 36–62). Experiments were made to study the nature of fatigue in steel and its recovery by heat treatment. Steels become brittle by the repetition of stresses exceeding a certain value, but recover their toughness after suitable treatment. The tensile properties are not so seriously affected. Repeated stresses cause slipping in the crystals themselves as well as at their boundaries, and between the steel and any included slag particles.

D. J. McAdam, jun., *Stress-Strain Cycle Relationship and Corrosion-Fatigue of Metals* (Paper read before the American Society for Testing Materials, June 1926). The first part of the paper outlines the investigation and describes the materials and methods used. The investigation was carried out on Monel metal, ingot iron, stainless iron, carbon steel, nickel steel, and chrome-nickel steel. Part 2 discusses the stress-strain-cycle relationship. The following subjects are considered: The stress-cycle graph extended to nominal stresses well above the tensile strength of the material and over a range from less than 1000 to more than 100,000,000 cycles; interrelationship between the stress cycle, stress deflection, and deflection-cycle graphs; effect of cyclic repetition on deflection and hysteresis; the stress-cycle graph as affected by cycle frequency, thermal conductivity of specimen and environment, and form of specimen; extrapolation of stress-cycle graphs. Part 3 discusses corrosion fatigue. Evidence is presented that very slight corrosion when simultaneous with fatigue causes low resistance to fatigue. The damaging effect is greater the harder the steel. The advantage of heat treatment may thus be practically neutralised. Ratios of "corrosion fatigue" limits to the endurance limit are compared with other physical properties of steel. The practical importance of corrosion fatigue for ferrous and non-ferrous metals is discussed.

H. A. Stacy, *Bend Tests of Galvanised Sheet Steel* (Paper read before the American Institute of Mining and Metallurgical Engineers, Oct. 1926). In an attempt to draw up a specification for galvanised sheet steel, the Federal Specifications Board carried out a series of tests on the following points: (1) The minimum mandrel thickness, expressed in terms of the thickness of the sheet tested, over which sheets with different weights of coating can be bent through 180° without serious damage to the coating; (2) the minimum radius of curvature on the inside of the angle in 90° bends in such material; (3) the effect of double seaming on the coating; (4) uniformity in the thickness of coating over a sheet, particularly as relates to the results of bend tests. The material and test procedure are described with diagrams and discussed. Stripping and bending test data for a large number of 16- and 22-gauge sheets of different coatings are given. A proposed clause covering bend properties is also included.

Material Bend Tests (Machinery, Aug. 12, 1926, vol. 28, p. 557). The lack of standardisation in bend testing is discussed, and the dimensions and requirements of a bend test commonly prescribed by

the Admiralty are quoted. The effect of improper machining and grinding on the test-piece is described, and the importance of the temperature at which the pieces are tested is noted.

H. Carrington, *Bending and Torsional Strains and Stresses in a Loaded Crankshaft* (Engineer, May 21, 1926, vol. 141, pp. 520–521).

S. H. Ingberg and P. D. Sale, *Compressive Strength and Deformation of Structural Steel and Cast-Iron Shapes at Temperatures up to 950° C.* (Paper read before the American Society for Testing Materials, June 1926). The authors present the results of tests on typical rolled steel shapes and one round hollow cast-iron shape, the tests being confined to structural steels of soft and medium grades and to grey cast iron. The results show a considerable rise in strength over the cold strength in the region of 250° C. Beyond 400° and 500° C. there is a decided decrease in strength, failure under working loads ordinarily applied taking place in the region of 500° to 700° C. A study of the effect of duration of load on ultimate strength at different temperatures is also included.

F. Riedel, *Stresses in Material Produced by a Circular or Annular Cutting Tool, as in the Punching Operation* (Stahl und Eisen, May 20, 1926, vol. 46, pp. 684–685). The article consists of a review of an investigation by E. L. Bach (doctor's thesis, Technical High School, Karlsruhe, 1923). Riedel points out, however, that, though the work appears to deal only with a special instance of stress occurrence, the results are of general interest, as they afford an example of slip-plane formation and the nature of the deformations ensuing. The distribution of stresses in punching a hole through a thick plate is considered, and the lines of stress are rendered visible by etching with Fry's reagent. The recrystallisation changes at the various stages of penetration of the punch are clearly brought out by etching.

B. D. Saklatwalla and H. T. Chandler, *Application of the Mathematics of Probability to Experimental Data as a Basis for Appropriate Choice of Ferrous Materials* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 195–213). The authors suggest a method of reasoning which should be of practical value in the selection of the most suitable steel. The "law of error" and the "law of frequency" are considered. Probability curves are given in which Brinell hardnesses are plotted against the "frequency number" of castings in foundry practice. This graphic method of representation gives more satisfactory results than mere averages of numbers.

H. O'Neill, *Hardness and its Relation to the Working and Machining Properties of Metals.—Part I.* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 233–279). The author has made experiments to determine what local deformations occur when a specimen is pressed upon by an indenter, and to demonstrate the mutual relationships existing between the results obtained by the ball, pyramid, and cone methods of testing for hardness, with their relative merits and demerits. Soft metals and viscous flow during indentation testing, the

apparent softening after cold-working, and the "pressure of fluidity," are also dealt with. In an appendix the author puts forward a suggested standard loading for Brinell ball testing.

R. C. Brumfield, *Some Comparisons between Rockwell and Brinell Hardness* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 841–856). The author presents the results obtained in testing both hard and soft metals by the Rockwell and Brinell hardness tests, and establishes the relation between Brinell hardness and each type of Rockwell hardness, in which the most influential factor is the area of contact with the piece under test. A table showing comparative Rockwell and Brinell hardness for various metals, including carbon steel, is given.

B.S. Tables of Brinell Hardness Numbers (British Engineering Standards Association, Publication No. 240, 1926). Standard tables of Brinell hardness numbers are given. Recommendations are given in regard to the accuracy of the apparatus to be used for the test, the preparation of the test specimens, the magnitude and application of the load, and the method of specifying the hardness.

Brinelling (Machinery, Oct. 21, 1926, vol. 29, pp. 87–88). Notes on the application of the Brinell hardness test, showing the manner in which inaccuracies may creep in.

Hardness Testing (Automobile Engineer, Aug. 1926, vol. 16, pp. 288–289). After referring to the difficulty of giving an exact definition of "hardness," the Brinell and Scleroscope methods of hardness testing and the Saniter test are described, and their limitations pointed out.

A. R. Page, *Testing Metals for Hardness* (American Machinist, European Edition, Sept. 18, 1926, vol. 65, pp. 66–68). The Brinell, diamond pyramid, and Rockwell methods of hardness testing are briefly discussed, and the applications of the tests are noted. Some of the anomalous indications which the tests sometimes show are mentioned.

K. Tamura, *On the Hardness of Different Structures in Steel* (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1926, No. 67). The relative proportions of carbon and manganese necessary to produce an austenitic structure in carbon steel by water-quenching was determined. The hardnesses of austenite and martensite at room temperature in a 1·69 carbon steel were found to be 155 Brinell and 720 Brinell respectively. The hardness of austenite in carbon steel at high temperatures was measured in a Honda-Sato impact hardness machine, and the result reduced to the Shore scale. At 820° C. the hardness was found to be 10 Shore. The average hardness of austenite in manganese steel at room temperature was determined at 180 Brinell, and at 820° C. was found to be 17 Shore. The relation between the hardness of martensite and the length of martensite needles was also investigated. The hardness of the martensite increases as the length of the martensite needles diminishes. The hardness of strained cementite was found to be 820 Brinell, and its natural hardness to be

640 Brinell. The variation of hardness in carbon, nickel, and manganese steels with temperature was measured, and the relation of the hardness of quenched steel with regard to the carbon concentration, and the relation between the hardness of a quenched carbon steel and the tempering temperature, were also determined.

M. Spindel, *The Resistance to Wear of Railway Material* (Zeitschrift des Oesterr. Ingenieur- und Architekten-Vereines, 1926, vol. 78, pp. 99–105; Zeitschrift des Vereines Deutscher Ingenieure, 1926, vol. 70, p. 415). A wear-testing machine devised by the author is illustrated and described. Diagrams of the wear of rails and parts such as brake blocks and tyres are automatically recorded, and results of tests are shown to be in agreement with the behaviour of the material under working conditions. Deductions as to resistance to wear of a steel cannot safely be drawn from the results of tensile tests or the manganese content.

Abrasion Testing (Metallurgist, June 25, 1926, pp. 83–84). An abstract in English of the paper by Spindel above referred to.

A. Dormus, *Note on Wear of Rails* (Stahl und Eisen, July 15, 1926, vol. 46, pp. 948–952). Rails which had been long in use on the Arlberg railway and on the Bozen Meran railway were tested for their wear properties with Spindel's wear-testing machine. Though the machine does not appear to give quite accurate results, it is conclusively shown that modern basic steel rails have a much greater resistance to wear than basic rails of thirty to forty years ago.

M. Susuki, *On the Abrasion of Carbon Steels* (Kinzoku no Kenko, 1926, No. 3, p. 149). The author has measured the coefficients of abrasion of different types of hypo-eutectoid carbon steel. Both the standard and relative coefficients were observed.

E. Buckingham, *The Relation of Load to Wear on Gear Teeth* (American Machinist, European Edition, June 26, 1926, vol. 64, pp. 777–780). Experiments have shown that for the transmission of power without appreciable wear on the gear teeth concerned the maximum specific stress given by the Hertz equation should not exceed the elastic limit of the material of the teeth.

D. W. Berlin, *Some Determinations of the Specific Gravity of Iron and Low-Carbon Steel in a Molten Condition* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 1–15). The investigations here reported form a continuation of the researches of Benedicks, Berlin, and Phragmén, and the apparatus originally used by them has been considerably improved. Graphs of the results of specific gravity determinations at various temperatures above the melting points of the four specimens used suggest that the relation is linear, but, in view of the great difficulties attending the performance of the experiments, the author puts forward the values obtained in a purely tentative manner.

P. Chevenard, *Dilatometric Anomaly of Paramagnetic Nickel-Chromium Alloys* (Comptes Rendus, 1926, vol. 182, pp. 1281–1283).

Commercial nickel-chromium alloys show an anomaly in the dilatation curve near a temperature of 550° C., which is not perfectly reversible. A new alloy, "Pyros," has been compounded in which the manganese content has been increased and iron and tungsten have been added, the composition being: nickel 82, chromium 7, tungsten 5, manganese 3, iron 3 per cent. In this alloy the anomaly is almost completely suppressed, and the alloy is recommended for use for standard bars for comparison purposes.

A New Form of Differential Dilatometer (Metallurgist, May 28, 1926, pp. 67–69). An illustrated abstract in English of an article by P. Chevenard in Revue de Métallurgie, Mémoires, Feb. 1926, vol. 23, pp. 92–99. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 641.)

J. T. Norton, *Welded Joints Searched by X-Rays* (Iron Age, Aug. 12, 1926, vol. 118, pp. 409–412). The application of X-ray examination to the study of welded joints is briefly described. The various types of defects common to welds are illustrated by radiographs, and the limitations of the method are considered as well as the advantages. The method will definitely show in the case of welded joints inclusions of gas, slag, oxides, or other impurities, whose thickness in a direction parallel to the X-ray beam is more than 5 per cent. of the total thickness of the sample. It will also show the presence of cracks or seams which are nearly parallel to the direction of the beam, and will indicate the failure of the welding material to join completely the base metals, but will not show cracks or layers which are normal to the beam.

A. St. John, *Mobile X-Ray Equipment* (Iron Age, Sept. 16, 1926, vol. 118, p. 783). Particulars are given of an X-ray installation which eliminates the use of a lead-lined room. The X-ray tube is enclosed in a lead-covered box or drum, of the proper shape and size, to give ample high-tension insulation and X-ray protection, and screens are provided around the power plant and high-tension connections. The X-rays are permitted to escape through windows of convenient size and shape and, after traversing the article under examination, are absorbed by lead shields. The author has used this type of installation for a number of years and has secured most satisfactory results in radiography, in fluoroscopy, and in crystal analysis.

1250-*Ton Testing Machine* (Engineer, July 30, 1926, vol. 142, pp. 114–116 and Supplement; Engineering, July 30, 1926, vol. 122, pp. 134–136, 138 and Supplement; Iron and Coal Trades Review, July 30, 1926, vol. 113, p. 165). This, the largest testing machine in the world, has been built by W. and T. Avery, Ltd., for testing in connection with the new Sydney Harbour bridge. Specimens up to 50 feet long, with a cross-section of 6 inches in diameter or 12 inches by 3 inches for tension members and up to 3 feet 9 inches by 3 feet 9 inches for compression members, can be tested. For transverse bending the maximum span is 20 feet, but the depth of the member may be as much as 50 feet, with a thickness of 3 feet 6 inches. The

ram has a stroke of 5 feet 6 inches, and is protected by a layer of electrolytically deposited copper.

Report of Committee E-1 on Methods of Testing (American Society for Testing Materials, June 1926). The Committee submit revisions of the tentative method of calibrating testing machines by means of an elastic calibration bar. A résumé is presented on impact testing, and a recommended procedure for impact testing is submitted. A report on the testing of thin sheet metals is also included.

M. F. Sayre, *A New Type of Mirror Extensometer* (Paper read before the American Society for Testing Materials, June 1926). The extensometer described is adaptable to routine testing of tension specimens of 2- or 8-inch lengths where a high degree of precision in proportional limit determinations is desired. The extensometer involves the use of a crossed spring suspension in place of the Martens rhomb, and the use of a system of four mirrors so placed as to average automatically the elongations on the two sides of the specimen. The optical system is such that no movement of the specimen affects the scale readings.

Universal Testing Machine (Iron Age, May 13, 1926, vol. 117, p. 1350). Brief particulars are given of the new Riehle universal, vertical, screw power testing machine of 1,000,000 lbs. capacity.

A Machine for making Repeated Shock Tests (Chaleur et Industrie, June 1926, vol. 7, pp. 351–352). A blow is struck by a hammer on the test-piece, which is in the form of a rod, supported on two knife-edges and is rotated through 180° after each blow. At the middle point of the test-piece a notch is cut to an exact diameter, to ensure that fracture shall take place at that point. The hammer delivers 70 to 100 blows per minute, a revolution counter recording the number. The height of fall of the hammer, the distance apart of the knife-edges, &c., are adjustable. The machine, which is operated by a small electric motor, has been used at the National Physical Laboratory.

A. Pomp and H. Schweinitz, *The Herbert Pendulum Hardness Tester and its Application to the Testing of Materials* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1926, vol. 8, No. 4, 22 pp.). The Herbert pendulum tester is described, and the four methods of using it are indicated. The deformations of the material which take place during the "time test" are studied in closer detail; an expression is derived for the "period of swing." The information gained concerning the deformations occurring during the experiment enabled relationships to be established between the Brinell and scleroscope hardnesses and the "time-test" hardness. The deformations arising during the test by measurement of the angle of oscillation of the pendulum are discussed. Experiments carried out with the pendulum on the various methods of test show that it is suitable only for the "time test."

A. Sauveur, *The Durometer—An Instrument for Testing Hardness* (Transactions of the American Society for Steel Treating, June 1926,

vol. 9, pp. 929–932, 1000). A brief description is given of this machine and its operation. A steel ball is dropped on to the specimen placed at an angle of 45°, and rebounds on to a glass sheet covered with graph paper and carbon paper, the position of its fall being recorded by a black dot on the graph paper. The precautions to be observed in operating the instrument are also outlined.

Methods of Hardness Testing (American Machinist, European Edition, Oct. 23, 1926, vol. 65, p. 501). A brief outline of the Rockwell hardness tester and its use.

J. H. Smith, *A New Twist Meter for Torsion Tests* (Paper read before the American Society for Testing Materials, June 1926). This instrument is for measuring the amount of twist in specimens under torsional stress, the principal advantages being that the instrument is quickly and accurately attached, the radius of the twist measuring arc is an accurately fixed quantity, and that errors in twist readings due to bending of specimens are entirely eliminated by means of universal joints in the yoke connector.

Spring Testing and Scragging Machines (Machinery, 1926, vol. 28; Sept. 16, pp. 724–725; Sept. 23, pp. 754–756; Sept. 30, pp. 789–790). A description of a variety of these machines manufactured by various makers.

British Standard Sections of Light Rails and Fishplates for Use in Mines (British Engineering Standards Association, Report No. 248, 1926). This Report covers both flat bottom and bridge rails.

A.S.T.M. Standards Adopted in 1926 (American Society for Testing Materials, Philadelphia, 1926). This pamphlet comprises the second supplement to the "Book of A.S.T.M. Standards" issued in 1924, and contains sixteen standards adopted by the Society. These include standard specifications for carbon tool steel, high-speed tool steel, alloy steel bolting material for high-temperature service, and aluminium for use in the manufacture of iron and steel.

Report of Committee on Specifications for Steel Castings (Transactions of the American Foundrymen's Association, 1925, vol. 33, pp. 698–704). The report contains the proposed tentative specifications for carbon-steel castings for valves, flanges, and fittings for high-temperature service issued by the American Society for Testing Materials.

Report of Committee A-1 on Steel (American Society for Testing Materials, June 1926). The Committee present new tentative specifications for marine boiler steel, commercial quality hot-rolled bar steels, commercial cold-finished bar steels and cold-finished shafting, cold-rolled strip steel, and forged or rolled steel pipe flanges and steel pipe for high-temperature service. Specifications for rails, springs, and pipe have been revised.

W. C. Wetherill, *Elimination of Waste in Industry* (Paper presented to American Drop Forging Institute at Annual Convention, May 1926: Forging, Stamping, Heat Treating, Aug. 1926, vol. 12, pp. 271–274). The author discusses what the U.S. Department of Commerce has

accomplished in the elimination of waste by the introduction of simplified practice and the suppression of procedure involving the duplication of labour, &c. A survey made by the Federated American Engineering Society assessed the average industrial waste at 49 per cent. The aim of the movement is simplification and standardisation. This paper was also presented to the Franklin Institute and appears in the Journal of the Franklin Institute, July 1926, vol. 202, pp. 1–22.

F. Rapatz, *The Performance of High-Speed Cutting Tools and their Testing* (Stahl und Eisen, Aug. 19, 1926, vol. 46, pp. 1109–1116). The results are reported of comparative cutting tests with high-speed tool steels of various quantities. The composition of the steels are stated, and diagrams show clearly the effect of different hardening temperatures and of varying the mechanical conditions of the tests on the durability of the tool.

E. G. Herbert, *The Measurement of Cutting Temperatures* (American Machinist, European Edition, Apr. 10, 1926, vol. 64, pp. 363–365). A supplement to a previously published paper (*see* Journal of the Iron and Steel Institute, 1926, No. I. p. 636 ; also American Machinist, 1926, vol. 64 ; Mar. 27, pp. 281–284 ; Apr. 3, pp. 307–310). Further tests indicate that the free-cutting range is a temperature effect, and a connection between the cutting temperatures, work-hardness, and the " Whitaker ring " is established.

H. Klopstock, *Recent Investigations in Turning and Planing and a New Form of Cutting Tool* (Transactions of the American Society of Mechanical Engineers, 1925, vol. 47, pp. 345–370). An account of experiments made to determine the influence upon the cutting forces of the following factors : Cutting speed, chip section, shape of tool, and characteristics of the materials cut. As a result a new form of tool has been designed, for which it is claimed that higher cutting speeds and larger chip sections are permitted.

On Effect of Tin and Arsenic on High-Speed Tool Steel (Report of Research Committee, American Society for Testing Materials, June 1926).

R. K. Barry, *Hardness and Toughness of High-Speed Steel as Affected by Heat Treatment* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 257–266). Hardness and deflection curves are given showing the effects of different heat treatments on a steel containing carbon 0·70, tungsten 17 to 18, vanadium 1, and chromium 3·50 per cent.

H. S. Rawdon and S. Epstein, *Observations on Phosphorus in Wrought Iron made by Different Puddling Processes* (Paper read before the American Iron and Steel Institute, May 21, 1926). The authors summarise the results obtained in the testing of several lots of wrought iron, produced by hand and mechanical puddling. The results are presented for their bearing on the effect of phosphorus on the properties of wrought iron. Tensile, torsion, single blow impact and repeated impact tests as well as the nick-bend test were used in the experiments. The results

are of particular interest in showing that the distribution of the phosphorus in a wrought iron bar may be of very much more consequence in determining the properties of the bar than is the average phosphorus content of the iron. Numerous photomicrographs show the various features in the structure of the irons tested. The results of the limited number of tests which were possible on the irons representative of the two puddling processes will not permit the drawing of any general conclusions regarding the relative merits of the processes. On the other hand, it may be pointed out that nothing was found to suggest that wrought iron cannot be made by a mechanical puddling process of the type used, fully equal to that produced by hand-puddling. It is also stated that the phosphorus content of the raw material can be reduced to a lower value more readily by the mechanical puddling process carried out on a relatively large scale than by the ordinary hand-puddling process. Variations in properties may occur within a single bar, particularly if the phosphorus content is somewhat above the normal value.

B. B. Wescott, *Quality Depends on Base Metal* (Iron Trade Review, Aug. 12, 1926, vol. 79, pp. 380–382, 388). A comparison is made between the characteristics of genuine wrought iron and that produced from an admixture of scrap. A number of photomicrographs are given showing the differences in structure. The weldability of the adulterated iron is lessened by the deficiency of slag and the variations in composition between adjacent sections of the material. Its resistance to fatigue is much lower than that of wrought iron, and it does not possess the ability to withstand corrosion successfully.

Properties of Alloy Steels (American Machinist, European Edition, July 10, 1926, vol. 64, p. 873). The composition and properties of the following alloy steels are briefly noted: Manganese steel, nickel steel, chrome steel, vanadium steel, tungsten steel, molybdenum steel, and high-speed steels.

Characteristics of Alloy Steels (American Machinist, European Edition, Aug. 7, 1926, vol. 65, p. 29). The properties of the metal vanadium and of steel alloys into the composition of which it enters are briefly reviewed, and some of the special uses to which the steels are put are enumerated.

A. Osawa, *The Relation between Space-Lattice Constant and Density of Iron-Nickel Alloys* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 387–398). This paper was first published in the Journal of the Iron and Steel Institute, 1926, No. I. p. 447. The text is again presented in substantially the same form, but much of the tabular matter and one diagram are at variance with those included in the original paper.

The Alloys of Iron and Tin (Metallurgist, May 28, 1926, p. 69). An abstract in English of a paper by Wever and Reinecken which appeared in Zeitschrift für Anorganische und Allgemeine Chemie, Mar. 12, 1926, and in Mitteilungen aus dem Kaiser-Wilhelm-Institut

für Eisenforschung, 1925, vol. 7, pp. 69–79. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 655.)

Effect of Phosphorus and Sulphur in Steel (Report of Committee, American Society for Testing Materials, June 1926). The conclusions presented by the Committee may properly be considered valid only for the type of rivet steel used in the investigation. This contained 0·09 to 0·15 carbon, 0·35 to 0·64 manganese, 0·005 to 0·035 phosphorus, 0·002 to 0·057 silicon, and 0·04 to 0·18 per cent. sulphur. The details of the investigation were presented in previous reports in 1922 and in 1924. Practically all the ingots and billets rolled satisfactorily, including the ingot from the high sulphur heat. It is stated that sulphur present in commercial rivet steel up to at least 0·06 per cent. is not detrimental, the tests showing no systematic relation between any of the physical properties determined and the sulphur content up to 0·06 per cent. With the sulphur content above approximately 0·06 per cent., the values of certain properties decrease with the increase in sulphur content.

J. H. Hall, *Manganese in Cast Steels* (Paper read before the American Foundrymen's Association, Sept.–Oct. 1926). The paper opens with a summary of the work of previous investigators of the constitution of iron-manganese alloys, and Guillet's diagram is reproduced with modifications. The major portion of the paper consists of data of the physical properties of cast manganese steel of the following composition: Carbon 0·2 to 0·3 per cent., and manganese from 1 to 2 per cent. Particulars are given of the elastic properties, shock toughness, and endurance strength. Stress-strain diagrams are given of heat-treated Orbit steel and commercial cast steel. The relative shock toughness of the heat-treated special steel and commercial carbon cast steels of various carbon contents are included. The relative effect of high manganese and of vanadium in cast steels is also shown. A table is included to show the relatively low toughness and shock strength of high-carbon cast nickel-chrome steel, and also that the Charpy value obtained from a heat-treated forged nickel steel is about the same as that of the heat-treated cast Orbit steel.

E. H. Schulz, *The Properties of High-Silicon Structural Steel* (Zeitschrift des Vereines Deutscher Ingenieure, June 19, 1926, vol. 70, pp. 860–864). The properties and applications of the high-silicon steel as developed by Freund are described. The composition and tensile properties of the material are stated. (*See also* Stahl und Eisen, April 15, 1926, vol. 46, pp. 493–503; Abstracts, Journal of the Iron and Steel Institute, 1926, No. I. p. 639; and Metallurgist, June 25, 1926, pp. 84–85.)

E. H. Schulz and H. Buchholtz, *Properties of High-Silicon Steel* (Paper read before the Verein deutscher Giessereifachleute: Foundry Trade Journal, Aug. 26, 1926, vol. 34, pp. 185–186).

H. W. Gillett, *Silicon as an Alloy in Steel* (Iron Age, Aug. 9, 1926, vol. 118, pp. 481–482). The author discusses the properties of

"Freund" steel, a low-carbon high-silicon steel produced in the Bosshardt furnace, and a comparison is made with other steels of similar composition. Recent investigations carried out in Germany (Stahl und Eisen, 1926, vol. 46, p. 493) show definitely that "Freund" steel can be made in furnaces other than the Bosshardt. The term "new" applied to "Freund" steel appears to be a misnomer as regards metallurgical knowledge of steel of high-silicon content, although quantity production of high-silicon steel of quite as low a carbon content as the "Freund" steel does not yet appear to have been undertaken outside Germany. The outstanding feature of the "Freund" steel is its composition, about 1 per cent. silicon and not over 0·15 per cent. carbon, the combination giving a high yield point and high ductility. A table is given showing the properties of the steel and other structural steels, from which it is seen that high yield point and high ductility may, with sufficiently low carbon, be obtained, by raising either the manganese or silicon content or by the use of nickel.

G. Phragmén, *The Constitution of the Iron-Silicon Alloys* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 397).

Heat Resistant, Acid Resistant, and Stainless Steels.—H. J. French, *Metals to Resist Corrosion or High Temperatures* (Paper read before the American Electrochemical Society, Oct. 1926: Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, pp. 591–593). The author discusses some of the principal characteristics and typical applications of metals used industrially to resist high temperatures and corrosion. The corrosion-resistant metals considered are aluminium, copper, brasses and bronzes, nickel and its alloy with copper and chromium, lead and lead-antimony alloys, tin, silver, zinc, ordinary irons and steels, ferro-silicons, nickel steels, and high-chromium steels. The metals for service at high temperatures are cast irons, malleable iron, ordinary steels, special steels, nickel and nickel-copper alloys and "heat-resisting" alloys. The paper is primarily a résumé of previously published information, and somewhat more emphasis is placed upon industrial applications than on laboratory test data. A selected bibliography of literature on the subject is appended.

Sir R. Hadfield, *Economising in Fuel and Material. Use of Special Steels* (Iron Trade Review, 1926, vol. 78; June 17, pp. 1561–1564; vol. 79, July 1, pp. 9–11). A general discussion of the many applications of heat-resisting and non-scaling steels. Mention is made of the new special steel developed by Hadfields, Ltd.

T. G. Elliot and G. B. Willey, *Chemically Resistant Steels, with Special Reference to Very High and Very Low Temperatures* (Paper read before the Congress of Chemists, July 20, 1926: Chemistry and Industry, July 30, 1926, pp. 526–534). The authors describe the properties of new types of alloy steels. The heat-resisting steel known as Era H.R., in addition to very marked non-scaling qualities, offers

great resistance to corrosive gases and fumes. It possesses, when tested in the ordinary way, a tenacity of 19 tons per square inch at a temperature of 900° C., while at 700° C. its tensile strength is 31 tons per square inch. A special class of low-temperature steel has also been developed, which at − 195° has an elastic limit between 23 and 29, and a tensile strength between 41 and 48 tons per square inch. The material is of the non-rusting type, and is practically unattacked by cold acids. A third type, known as Era C.R. steel, is also of the non-rusting class of steels. It offers high resistance to attack by mine-water containing ferrous and ferric salts in solution, and it shows complete resistance to nitric acid of all concentrations and temperatures, to acetic acid, and to mixtures of nitric and sulphuric acid solutions used in various industrial processes. Sulphuric acid solutions up to 25 per cent. have but slight effect.

High-Temperature Engineering (Electrician, June 25, 1926, vol. 96, pp. 670–671). An account of the properties and uses of Hadfield's "Era" steel.

E. H. Schulz, W. Jenge, and F. Bauerfeld, *Latest Progress in the Sphere of the High-Duty Alloys* (Zeitschrift für Metallkunde, May 1926, vol. 18, pp. 155–158). The authors made magnetic and micrographic examinations of the heat treatment of an English cobalt magnet steel of the following approximate composition : cobalt 6 to 18, chromium about 9, molybdenum 2·5, carbon 1 per cent., remainder iron. The prescribed heat treatment was to heat at 1150° to 1200° C. for five minutes, and air-cool ; reheat in a furnace at 750° C. until the metal brightened and then became darker again, and then remove from the furnace ; finally place in a furnace at 1050° C., and as soon as the pieces reach 1000° C. remove and air-cool. The characteristics, behaviour at room temperature, applicability to gauges and draw-rings, and resistance to wear and corrosion, of alloys of the stellite type, are also dealt with.

M. Grard, *Influence of the Temperature Range of Working on the Choice of Metals for Aviation Motors. Application to Exhaust Valves* (Revue de Métallurgie, Mémoires, June 1926, vol. 23, pp. 317–330). The choice of metal for exhaust valves is an important but difficult problem. The requirements are many ; the temperature range during use is very wide, resistance to shock and oxidation, hardness and resilience must be high throughout the range, and the heat conduction and lightness must be the maximum possible. The author first reviews the thermal and mechanical conditions under which the valves have to work, and then indicates the effect of these conditions from the metallurgical point of view. He finally describes some experiments, carried out both in the laboratory and under conditions of use, made on a chrome-silicon steel. These steels contained 0·3 to 0·4 per cent. carbon, 2 to 4 per cent. silicon, and 12 to 14 per cent. chromium. It is shown that the good test results obtained on valves made of these alloys are due to the fact that the transformation temperatures all lie

above the working temperature range, so preventing the occurrence of molecular changes and fatigue.

Safe Stresses at High Temperatures (Metallurgist, July 30, 1926, pp. 104–106). The modern tendency towards the use of high pressures and high temperatures in boilers, turbines, &c., makes a knowledge of the probable behaviour of the materials to be used at high temperatures increasingly necessary. The most reliable guide, so far, appears to be the creep strength of the material, and the results of tests of this characteristic by various investigators are recorded and compared. Little information is at present available concerning endurance to fatigue at high temperatures. At such elevated temperatures the maintenance of exact conditions becomes more difficult, and yet this exactness is of the utmost importance; an alteration of the temperature by a few degrees, for instance, may make very large differences in the results obtained. In the creep test also due care must be taken of the increase of load per unit area which occurs when the specimen elongates.

H. E. Weightman, *Protecting Furnace Parts from Oxidation* (Forging, Stamping, Heat Treating, June 1926, vol. 12, p. 196). The older method of protecting metal surfaces by spraying with aluminium is often inapplicable to furnaces, owing to the inaccessibility of the metal to be treated or to the great heat of the furnace even when not in operation. The author has devised a new process in which the metal to be coated is freed from oil, grease, and sand, and is then dipped in a slip made of an aluminium-iron-titanium mixture with sodium metasilicate. For parts already in position the slip may be painted on or sprayed on with an ordinary paint-spraying machine. Tests made with the new protective coating are described.

E. Morgan, *Notes on Tests for Heat-Resisting Irons* (Bulletin of the British Cast-Iron Research Association, Oct. 1926, No. 14, pp. 16–19).

M. A. Grossmann, *Behaviour of Carbon in a High-Chromium Rustless Iron* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 436–446). An equilibrium between alpha-iron and austenite was observed in an annealed rustless iron (chromium 17·5 per cent., carbon 0·08 per cent.) at high temperatures. Areas in which carbides were concentrated would, upon heating, form austenite, but no amount of further heating would cause any absorption of alpha-iron by the austenite. The austenitic areas resulted, upon cooling, in an austenite-martensite structure. The martensitic areas existed as hard regions in a plastic matrix of alpha-iron. This reduced materially the ductility of the metal, although not greatly increasing its Brinell hardness. The existence of numerous minute carbide particles embedded in the alpha-iron was deduced from the irregularity of slip-bands and from the results obtained in carburising the steel. The carbide particles were in part the result of precipitation of carbide when alpha-iron grains encroached into austenitic areas at high temperatures.

C. E. Macquigg, *Chromium Alloys Resist Chemicals* (Paper read before the American Institute of Chemical Engineers, June 21, 1926: Iron Age, Aug. 12, 1926, vol. 118, pp. 416–418; Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, pp. 609–611). A discussion of the corrosion- and acid-resisting properties of chromium-iron alloys. The characteristic chromium alloys, their principal properties, and some of their typical applications are tabulated.

J. G. Thompson, *Resistance of Metals to Nitric Acid* (Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, pp. 614–616). A record of experiments, and results, on the attack by nitric acid on aluminium and its alloys, high-silicon and high-chromium steels, metallic chromium and chrome-nickel steels. Aluminium resisted concentrated acid well, but failed when the concentration fell below 68 per cent. For the lower strengths of acid a number of irons and steels were satisfactory, but they were unsuitable for the more concentrated acid. Over 14 per cent. silicon in cast irons, or over 16 per cent. chromium in steels, appeared to be necessary to impart corrosion resistance to all strengths of acid up to 68 per cent. Metallic chromium resisted attack up to 68 per cent. acid. High nickel did not improve the behaviour of chrome-nickel steels, and if over 20 per cent. it was definitely injurious. Molybdenum alone had no effect.

T. Meierling and W. Denecke, *The Three-Component System: Iron-Chromium-Carbon* (Zeitschrift für Anorganische und Allgemeine Chemie, 1926, vol. 151, pp. 113–120). The results are presented of a study of the iron-chromium-carbon system, with concentrations of carbon varying from 0·70 to 2·60 per cent., and of chromium from 0 to 20 per cent.

T. H. Nelson, *Recent Developments in the Use and Fabrication of Corrosion-Resistant Alloys* (Paper read before the American Society for Testing Materials, June 1926). The paper discusses particularly stainless iron and steel, their methods of manufacture, and the advantages of certain types of corrosion-resistant alloys for specific purposes.

N. L. Mochel, *Stainless Iron* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 353–394). The author discusses the characteristics of low-carbon chromium-iron alloys, with carbon not over 0·12 per cent. and chromium 10 to about 19 per cent. English, American, and Swedish steels were used in the tests. Data are given relative to physical properties of irons of varying compositions and with varying heat treatments. Special attention is paid to elastic limit and impact values. The effect of varying chromium content and of silicon, copper, and nickel on the physical properties, microstructure, resistance to corrosion, and workability is discussed.

W. S. Calcott, *Working Corrosion-Resistant Metals* (Paper read before American Institute of Chemical Engineers, June 21–24, 1926: Chemical and Metallurgical Engineering, Aug. 1926, vol. 33, p. 465). The paper shows how details of design may be of great importance in their effect on the life of corrosion-resisting plant. In some cases

only very slight differences in the treatment of a part may entirely nullify its resistance to attack.

F. Adcock, *The Effect of Nitrogen on Chromium and Some Iron-Chromium Alloys* (*Alloys of Iron Research.—Part IV.*) (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 117).

W. H. Hatfield, *Resistant Steels for Chemical Engineering* (Paper read before the Congress of Chemists, July 20, 1926: Chemistry and Industry, Aug. 13, 1926, pp. 568–573).

T. R. Wilton, *The Properties and Engineering Uses of Stainless Steel* (Paper read before the Liverpool Engineering Society: Electrical Review, Apr. 23, 1926, vol. 98, p. 658).

A. C. Yorke, *Stainless Steels and Iron* (Metal Industry, Oct. 29, 1926, vol. 29, pp. 419–420). A very brief description of the manufacture, composition, and properties of stainless steel.

Comparative Resistance of Mild Steel, Chromium Steel, and Chromium-Nickel Steel to Various Media (Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, p. 636). A table extracted from Dr. Hatfield's paper read before a joint meeting of the British Chemical Plant Manufacturers' Association and the Institute of Metals, July 20, 1926.

New Acid-Resisting Alloy (Iron Age, June 3, 1926, vol. 117, p. 1577). Brief particulars are given of a new acid-resisting alloy, known as Pioneer metal. It is composed of Armco iron with 35 per cent. nickel, 25 per cent. chromium, and about 5 per cent. molybdenum. The carbon content ranges from 0·20 to 0·30 per cent. It has a tensile strength of 74,000 lbs. per square inch in the cast condition. An outline is given of its manufacture, which is carried out in a basic electric furnace.

Rustless Iron (Foundry Trade Journal, Apr. 29, 1926, vol. 33, p. 328). Brief particulars are given of a new rustless iron known as Delhi Tough, developed by an American concern. No analysis is given, but the metal is stated to be low in carbon (averaging 0·07 per cent.) and high in silicon and chromium. The metal is non-corrodible and non-oxidisable when heated to temperatures not in excess of 980° C. A summary is given of the tests carried out by the Carnegie Institute of Technology.

The Use of the Non-Rusting Steel V2A in Hydraulic Work (Kruppsche Monatshefte, May 1926, vol. 7, pp. 85–87). The special non-rusting steel V2A has proved highly suitable for valves, spindles, and other moving parts in hydraulic machinery. Besides its resistance to corrosion, the steel is strongly resistant to wear.

Characteristics of Ascoloy (American Machinist, European Edition, May 22, 1926, vol. 64, p. 609). Ascoloy is a rustless iron of the following composition:

	Per Cent.		Per Cent.
Carbon	under 0·12	Chromium	12 to 16
Manganese	,, 0·50	Silicon	under 0·5
Sulphur	,, 0·025	Nickel	,, 0·5
Phosphorus	,, 0·025		

It is a malleable and ductile chrome steel alloy made in the electric furnace. The article describes its properties and mode of use.

K. Daeves, *Corrosion Resistance of Copper Steels of Basic Bessemer and Open-Hearth Origin* (Stahl und Eisen, May 6, 1926, vol. 46, pp. 609–611). After giving a short review of the extensive work of the American Society for Testing Materials on the corrosion resistance of steels containing varying percentages of copper and of Bauer's experiments on the same class of material, which yielded different conclusions, the author points out that the results are more clearly brought out by the use of the mass-result method of investigation. Applying this method he shows by means of diagrams that an addition of copper up to 0·25 per cent. considerably increases the resistance to corrosion of steel exposed to the atmosphere and in a rather less degree when embedded in soil. Basic Bessemer copper steel shows the highest resistance, that of open-hearth material being always somewhat lower. This is the case when the copper is artificially added in the process of manufacture, but open-hearth plates of Siegerland origin containing a natural percentage of 0·30 per cent. copper withstood corrosion equally well as the basic Bessemer plates to which copper had been added.

Corrosion Resistance of Copper Steels (Metallurgist, June 25, 1926, pp. 90–92). A brief summary and comparison of the results of Bauer, Daeves, Hadfield, and Friend.

Use of Pure Iron in the Gas Industry (Gas Journal, June 23, 1926, vol. 174, pp. 659–661). The conditions prevailing in the gas industry render it imperative to employ, for a wide range of purposes, material capable of withstanding, to an exceptional degree, corrosive influences. Armco iron is stated to meet this demand very satisfactorily, and examples of its use are cited.

Metallography, Crystallography, and Constitution.—*Report of Committee E-4 on Metallography* (American Society for Testing Materials, June 1926). The Committee present recommendations for the revision of the methods of metallographic testing of non-ferrous metals and alloys. A paper by E. C. Groesbeck on "*Etching Reagents for Carbides, &c., in Alloy Steel*" is submitted as part of the report. The Sub-Committee on micro-hardness report the results of an investigation of a method of scratch hardness testing, and publish a complete bibliography on the subject. The Sub-Committee on X-ray metallography submit a recommended practice for radiographic testing of metal castings, and present a glossary of terms used in radiography. A proposed recommended practice for the care of the eyes when using a metallographical microscope is also included.

F. P. Gilligan and J. J. Curran, *Macroscopic Examination of Iron and Steel* (Transactions of the American Society for Steel Treating, July 1926, vol. 10, pp. 9–30). The paper describes the deep etching method of inspection. The authors discuss in detail the procedure to be followed in using this method and the merits of the various acid mixtures used in detecting different types of defects. The authors present a large

number of photographs of specimens tested by this method and describe the nature of the defects revealed.

Haufe, *The Metallographic Detection of Phosphorus* (Kruppsche Monatshefte, Apr. 1926, vol. 7, pp. 66–69). The author has made comparative trials with a number of reagents to determine their respective efficacies in revealing the distribution of phosphorus on the etched surface of a steel section. The reagents used were those of Heyn, Stead, Rosenhain, Le Chatelier, Oberhoffer, and Fry, the composition being stated in each case. All of them contain a copper salt, usually in the form of copper chloride. The different effects of each are shown in photographs. The most satisfactory results are those obtained with Heyn's, Oberhoffer's, Fry's Solution No. II., Rosenhain's, and Le Chatelier's reagent. Stead's solution does not bring out the delicacy of the structure. Heyn's is the best for ordinary practical work, but if the copper deposit adheres to the surface, then Fry's and Oberhoffer's are preferable.

P. Oberhoffer, *A Specific Etching Reagent for Silicon in Iron* (Stahl und Eisen, Sept. 2, 1926, vol. 46, pp. 1191–1192). For the metallographic examination of iron alloys deoxidised with silicon, iodine was used among other reagents. Some remarkable figures were produced on the etched surfaces which could be reproduced again and again at will with the iodine but not with any other reagent. The best results were obtained with an alcoholic solution of 1 to 10 parts of $\frac{1}{10}$ normal iodine solution, and with an etching period of five to fifteen minutes. The effect could be heightened by light polishing after etching. Analyses showed that where the etching figures came out strongly the metal contained an appreciable amount of silicon (0·38 per cent. or upwards), and that in parts where the iodine solution brought out no figures there was practically no silicon present. It would appear that the iodine reacts to silicon but not to silica, but confirmation of this has not yet been obtained. The action of the new reagent is demonstrated by means of micrographs.

K. Honda, *On the Theory of Hardening of Metals* (Kinzoku no Kenku, 1926, No. 1, pp. 1–12). The author distinguishes two types of hardness: (1) Natural hardness of each individual crystal constituting metals; (2) the change of hardness as affected by external conditions or the state of aggregation of micro-crystals. The natural hardness is to be explained by the law of atomic force. The increase of hardness due to cold-working, increased fineness of grains, or interstrain, belongs to the second kind. These increases of hardness are explained, as well as the phenomena of blue brittleness and the temper hardening in quenched steels and cold-worked metals. The general belief that the distortion of the space lattice causes the hardening of metals is shown mathematically to be incorrect. Hence the increase of hardness in a continuous solid solution consisting of two components is explained by means of grain-size.

T. Kasé, *A Further Study of the Distribution of Hardness in Quenched*

Carbon Steels and Quenching Cracks (Science Reports of the Tôhoku Imperial University, Sendai, 1926, vol. 15, pp. 371–386). The conclusions drawn by the author as a result of the investigation are in agreement with those formed by Honda.

W. T. Griffiths, *The Hardening of Steel: A Review and Some Comments* (Metallurgist, 1926; Apr. 30, pp. 51–53; May 28, pp. 72–74; June 25, pp. 89, 90). Part I. appeared in the March number (*see* Journal of the Iron and Steel Institute, 1926, No. I. pp. 648, 649). In Part II. X-ray spectrographic examination is briefly reviewed, and a discussion of the Ar1, Ar2, and Ar3 points follows. The author doubts the existence of Ar3, because he has never obtained satisfactory evidence of Ar2 and Ar3 together in the cooling curve of any alloy steel, and because by suitable alteration of the initial conditions and rate of cooling Ar3 may be made to occur at temperatures covering a wide range. Part III. is devoted to a consideration of troostite, martensite, and austenite, their formation, structure, &c. Part IV. details briefly theories of the cause of the hardness of quenched steels. A useful bibliography is appended. The author also sets forth views on certain factors controlling the hardening of steel, for which he considers there is evidence available.

G. Sachs, *The Hardening of Metals* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, 1926, Special Series No. II., pp. 99–114; *see also* Zeitschrift für Metallkunde, 1925, vol. 17, p. 85; Abstract, Journal of the Iron and Steel Institute, 1925, No. I. p. 571). A general study of the phenomena of the hardening of metals. The hardening effect of cold-working is due to the disturbance of the lattice, distortion of the slip-planes, or the creation of a state of elastic tension. The measure of hardening effect is the magnitude of the internal stresses and the speed of their change from point to point. Recrystallisation follows when equilibrium between the internal stresses is brought about by internal rearrangement. Further conclusions are given in full.

H. Hanemann and A. Schrader, *On Martensite* (Berichte der Fachausschüsse des Vereines deutscher Eisenhüttenleute, Report No. 61, 1926, 25 pp.). This report was prepared in the metallographic section of the metallurgical laboratory of the Berlin Technical High School. A translation of it has now appeared in the Transactions of the American Society for Steel Treating. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 650.)

A. Pomp and R. Wijkander, *Influence of the Structural Form of Cementite on the Ability of Steels to Harden* (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1926, vol. 8, No. 2, 8 pp.). Besides the chemical composition and the usual factors in hardening, the structural form of the raw material has an important effect on the product of the hardening process. Cementite in the spheroidised condition may have a greater or less surface area than banded cementite in a steel of the same carbon content, depending

on the number of globules and on the width of the lamellæ. Calculations of the surface areas of both structural types in a eutectoid steel were made. Tests on eutectoid steel which had been suitably heat-treated to contain coarsely and finely laminated cementite and coarsely and finely spheroidised cementite, and had been heated for varying periods before quenching, showed that the speed of solution of the cementite, as measured by the resulting hardness, was not dependent solely on the calculated surface area of the cementite. The microscope revealed that whereas the globules of spheroidised cementite dissolved directly into the surrounding ferrite, the solution of the banded pearlite started at the boundaries of the grains and proceeded inwards. The unchanged cementite and ferrite lamellæ could be distinguished in the interior of the still undissolved pearlite grains. For this reason banded cementite needs a longer period of heating for complete solution than would be expected from a consideration of surface area only.

A. Sauveur, *Theories of the Hardening of Steel* (Revue de Métallurgie, Mémoires, 1926, vol. 23; July, pp. 392–406; Aug., pp. 446–462). A translation in full of the author's paper into French. (*See* Journal of the Iron and Steel Institute, 1926, No. I. p. 649.)

G. Sachs and E. Schiebold, *The Orientation of the Lattice in Deformed Metal Crystals and Crystal Aggregates* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, 1926, Special Series No. II., pp. 211–215).

K. Weissenberg, *The Structure of Crystals* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, 1926, Special Series No. II., pp. 216–279). A complete system is worked out for all dynamically defined atom groups within a crystal, such atom groups being termed "dynads." Tables have been compiled by means of which all atom groups of the crystal with a given lattice can be read off direct.

O. W. Ellis, *An Investigation into the Effect of Constitution on the Malleability of Steel at High Temperatures* (Iron and Steel Institute: Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 195–215). The following were the objects of the research: (1) To determine the influence of the A3 point on the malleability of pure iron; (2) to determine whether a change in the malleability of eutectoid steel occurs in the neighbourhood of 930° C.; (3) to determine the influence of the A4 point on the malleability of a low-carbon steel; and (4) to determine the malleability of medium-carbon steels at temperatures in excess of 1000° C. The results of the investigation are fully set out by means of tables, graphs, and micrographs.

F. Sauerwald, *The Scientific Conception of Some of the Properties of Metals of Importance in Casting and Hot-Working* (Zeitschrift für Metallkunde, 1926, vol. 18; May, pp. 137–142; June, pp. 193–195). The author reviews the properties of molten metals, such as viscosity, surface tension, molecular arrangement, and volume characteristics, their influence on casting, and their effect on the crystallisation of the metals. He also discusses the amount of work expended during hot-working and its relationship to the temperature, and gives a method of

estimating it by the measurement of another easily determined property of the metal. Crystallisation during and after hot-working, and its effect on the finished products, is likewise considered. The working of the metal has no practical effect on the position of the critical points and melting point of the metal.

A. Allison, *Spheroidisation and How it Occurs* (Iron Age, July 8, 1926, vol. 118, pp. 73–76). It is suggested that divorce of pearlite and spheroidisation of cementite, and grain growth, are reciprocal processes; also that annealing after straining is the common cause of these phenomena, by the formation of definite crystals from slip-bands and the growth of these crystals upon the strained portion of the original crystals. Large grain-size corresponds with weak material, on account of the less frequent change of direction of the stress applied, and the strength resulting from small grain-size is produced by the more numerous adjustments of the lines of force. Slight straining in coarse-grained material is sufficient to cause brittleness by reason of the large area of the slip-planes.

B. Stoughton and R. D. Billinger, *The Spheroidising of Cementite* (Industrial and Engineering Chemistry, Aug. 1926, vol. 18, pp. 785–788). The old Damascene swords owed their excellence to the cementite being spheroidised. Nowadays that condition is attained by heat-treating the steel at a temperature close to the Ac1 point. The authors review the earlier work on spheroidisation, and show that the temperature range suitable for the heat treatment is wider than was previously thought. They consider hyper-eutectoid, eutectoid, and hypo-eutectoid steels through several ranges of temperature.

B. Stoughton and F. J. G. Duck, *A Study of Dendritic Structure and Crystal Fracture* (Transactions of the American Society for Steel Treating, July 1926, vol. 10, pp. 31–52). The authors discuss the formation of dendritic crystals in overheated high-carbon steel, and present a study of such crystallisation. The intercrystalline rupture of the overheated steel is offered as evidence that the amorphous theory does not hold good when the crystals are large and there are correspondingly large surfaces of cement. Following out this reasoning, the rupture of metals through the intercrystalline cement at high temperatures may be due to the large size of the crystals at those temperatures, as contrasted with their size at atmospheric temperature. It seems probable that the small crystals, as well as the inter-lamellar crystals, that occur throughout the eutectoid areas were formed as a result of the tremendous pressure brought about by the expansion of the material in its change from austenite to pearlite. Several photomicrographs are presented in support of these conclusions. It is also stated that the Brinell hardness numbers of any steel vary inversely as the size of its constituent crystals, although no attempt is made to show any relation between them.

J. R. Freeman, *Recrystallisation Temperatures of Cold-Rolled Electrolytic Iron and Open-Hearth Strip* (Transactions of the American

Society for Steel Treating, July 1926, vol. 10, pp. 67–86). The author has studied the respective temperatures of recrystallisation of electrolytic iron and open-hearth steel especially selected for deep drawing operations. The investigation is a continuation of a previous one (U.S. Bureau of Standards, Technologic Paper No. 288) of the cold-rolling characteristics of the two types of materials. Tensile tests and microstructural studies were made of strip subjected to different amounts of work by cold-rolling, and annealed at progressively increasing temperatures. It was found that electrolytic iron underwent a marked recrystallisation when annealed for half an hour at 930° F. (500° C.), coincident with a pronounced decrease in tensile strength. Incipient recrystallisation was noted in a specimen annealed for twenty-four hours at 750° F. (400° C.). In the open-hearth steel a similar marked recrystallisation coincident with a decrease in tensile strength was observed in specimens annealed at 1110° F. (600° C.), while no marked change was observed in specimens annealed for half an hour at 930° F. (500° C.).

S. C. Spalding, *Effect of Reheating on Cold-Drawn Bars* (Transactions of the American Society for Steel Treating, May 1926, vol. 9, pp. 685–716, 780). The author describes the results of an investigation carried out in order to determine the effect of reheating at low temperatures on cold-drawn alloy steel bars. Three steels were used—a carbon-manganese steel, a 3·5 per cent. nickel steel, and a chrome-vanadium steel. The carbon content of all the steels was between 0·20 and 0·30 per cent. Hot-rolled bars were drawn in one draft from three different sizes to one finished size, thus effecting different amounts of cold-work. The tensile strength, impact resistance, hardness, and electrical conductivity of the bars were investigated in the hot-rolled, cold-drawn and reheated, and quenched and reheated condition before and after cold-drawing. The general conclusions are as follows: The yield points of the steels are considerably increased after cold-drawing and reheating to 315° C. The tensile strength is only slightly increased. There is a slight loss in the ductility and notched-bar toughness. At 540° and 595° C. the yield point and tensile strength are reduced to their initial figures, while the ductility and notched-bar figures have increased. Reheating over 595° C. causes the yield point and tensile strength to fall rapidly and the ductility and notched-bar figures to increase. The chrome-vanadium steels require a higher reheating temperature to restore their normal physical condition.

The Measurement of Cold-Work (Machinery, Oct. 14, 1926, vol. 29, p. 49). A very brief notice of the three methods of measuring and expressing cold-work suggested by Grard, Anderson, and Hanriot respectively.

G. I. Taylor and C. F. Elam, *The Distortion of Iron Crystals* (Proceedings of the Royal Society, 1926, (A), vol. 112, pp. 337–361). The work described in this paper shows that the mechanism of distortion in iron crystals is subject to laws unlike those governing the

slip phenomena in any metal hitherto investigated. The particles of the metal stick together along a certain crystallographic direction, and the resulting distortion may be likened to that of a large bundle of rods which glide on one another. The rods stick together in groups or smaller bundles of irregular cross-section ; the slip lines which appear on a polished surface are the traces of these bundles on that surface. When the distortion of the crystal in bulk is a uniform shear the bundles stick together to form plates of irregular thickness, but lying in general with their planes parallel to the plane of slip determined by external measurements of the surface. The plane of these plates is determined by the direction of the principal stress, and has no direct relationship with the crystal axes. This conception appears to explain the nature of slip lines, and has enabled the authors to predict the hitherto unknown fact that if the crystal be cut with a polished surface parallel to the direction of slip, the slip lines will all be straight, but that when there is an appreciable angle between the polished surface and the direction of slip the slip lines are jagged or curved.

H. C. H. Carpenter, *The Production of Single Crystals of Metals and Some of their Properties* (Journal of the Institute of Metals, 1926, No. 1, pp. 409–438). After many trials single crystals were produced in sheets from test-pieces of aluminium. The original test-piece measured $4 \times 1 \times 0{\cdot}125$ inches. It was first accurately machined along the parallel sides, after which three treatments were necessary to convert it into a single crystal. The first treatment was thermal, with the object of softening the metal, the specimen being heated at 550° C. for six hours. The second treatment was mechanical, the strip being strained to an elongation of 1·6 per cent. on 3 inches. The final treatment was again thermal. It was begun at 450° C., and the temperature was raised at about 25° C. per day up to 550° ; it was finally brought up to 600° for one hour. It was found that on an average one test-piece in four was converted into a single crystal in this way, the total time for the crystal to grow being 100 hours. Single crystals in round bars could be produced by similar treatment, but it was not found possible to produce single crystals in square bars.

L. B. Pfeil, *The Deformation of Iron, with Particular Reference to Single Crystals* (Iron and Steel Institute : Carnegie Scholarship Memoirs, 1926, vol. 15, pp. 319–380). A method of growing large crystals in ½-inch diameter rods is described ; the largest crystal so obtained was 5½ inches long. Both finely crystalline material and large crystals were used in the study of the nature and mode of formation of Neumann lamellæ produced by impact. The force of the impact determined the position of the lamellæ, the direction of the blow in relation to the crystal orientation being without effect. After slow deformation the lamellæ were no longer producible by shock, but low-temperature annealing removed the effect of the deformation. A step is produced on the polished face of a crystal by the formation of a lamella, and may

also be produced by the intersection of two lamellæ. Prolonged high-temperature annealing does not destroy the lamellæ; they are concluded to be twin crystals, and the necessary atomic movements for their production are suggested. The relation between elastic limit, compressive strength, and orientation are discussed. In an iron crystal slip occurs on icosetetrahedral planes in the direction of the trigonal axes parallel to those planes. While a crystal may be cold-worked to a considerable extent without structural alteration, severe working has marked effects, which are concluded to be due to mechanical twinning; the latter results from both compressive and tensile deformation, the degree of twinning being dependent upon the orientation and amount of deformation. Experiments were performed which indicate the nature of the movement by which twins are produced, and their relation to Neumann lamellæ is discussed. The very large crystals grown in iron strips tend towards one orientation, and the orientations of crystals grown in round bars are considered in the light of that fact.

C. H. Desch, *The Growth of Crystals* (Lecture to the Royal Institute, Mar. 16 and 23, 1926: Nature, May 15, 1926, vol. 117, pp. 694–695). The process of crystal growth on minerals and metals is described in the light of recent research.

L. Grenet, *Remarks on the Iron-Nickel Diagram—Irreversibility of the Crystalline Transformations—Quasi-Limiting States in the Crystallised Bodies* (Revue de Métallurgie, Mémoires, July 1926, vol. 23, p. 432). A supplementary note to the article appearing under the above title in Revue de Métallurgie, Mar. 1926, vol. 23, pp. 143–153.

E. Houdremont, H. Kallen, and K. Thomsen, *Cold-Working and Recrystallisation of Treated Steels* (Stahl und Eisen, July 22, 1926, vol. 46, pp. 973–976). The effect of cold-drawing on heated and quenched steels and on alloy steels has been studied. Such steels are more suited for cold-drawing operations than annealed steels, probably on account of their finer and more homogeneous structure. Curves showing the effect of cold-working on the tensile properties of quenched steels are given, as well as curves indicating the effect of annealing after cold-working.

E. Schiebold, *Cold-Working Phenomena in the Light of X-Ray Research* (Mitteilungen aus dem Materialprüfungsamt, Berlin-Dahlem, 1926, Special Series No. II., pp. 61–69; *see also* Zeitschrift für Metallkunde, 1924, vol. 16; Nov., pp. 417–425; Dec., pp. 462–480; Abstract, Journal of the Iron and Steel Institute, 1925, No. I. p. 572). The theories of plastic deformation and cold-working effect are considered from the point of view of crystal structure, which at present is only accessible by means of Röntgen rays. On the basis of the general principle of the change of orientation it has been possible to co-ordinate the existing theories into one in which the conception of the combination designated "bend-slipping" is rendered quite distinct from ordinary and crystalline geometrical change of orientation. But even this theory is still unsatisfactory from the exact point of view of geometric

crystallography, and a much more precise refinement is necessary. A full bibliography of the literature on the subject is given.

W. L. Webster, *The Longitudinal Magneto-Resistance Effect in Single Iron Crystals* (Proceedings of the Royal Society, Nov. 1926, vol. 113, (A), pp. 196–207). The change of resistance in a longitudinal magnetic field was measured for three directions in single crystals of iron. For the (100) axis there was no change of resistance; for the (111) axis no change occurred till a magnetic intensity of 800 c.g.s. was reached; for the (110) axis the change was similar to that of the (111) axis, but the limiting value of dR/R was less. It is suggested that the change was due to an alteration of the orientation of the atoms when the iron was magnetised. The bearing of these results on the phenomenon of magneto-striction is discussed, and an explanation of the apparent connection between them put forward.

F. S. Goucher, *Deformation of Tungsten Single Crystals* (Phil. Mag., 1926, Series 7, vol. 2, pp. 289–309). Individual crystals in pure tungsten wires were annealed at 3100° K., and their deformation under constant load was determined at 2000° and 1000° K. An X-ray study of the crystals reveals distortion of a crystallographic nature, which is roughly proportional in amount to the deformation, and is not altered on annealing.

Primary Crystallisation in Nickel-Chromium Steels (Metallurgist, June 25, 1926, p. 83). An abstract in English of a paper by F. Leitner in Stahl und Eisen, April 22, 1926. (*See* Journal of the Iron and Steel Institute, 1925, No. I. p. 656.)

J. Young, *The Crystal Structure of Meteoric Iron as Determined by X-Ray Analysis* (Proceedings of the Royal Society, 1926, vol. 112, (A), No. A762, pp. 630–641).

G. Tammann and W. Riedelsberger, *Chladni Figures on Rolled Sheets* (Zeitschrift für Metallkunde, 1926, vol. 18; Apr., pp. 105–111; May, pp. 149–154). This article reports the continuation of earlier work carried out by Tammann and Schroeder (Zeitschrift für Metallkunde, 1924, vol. 16, pp. 201–206), and describes the application of acoustic tests to discs of rolled sheet metal. The plates are suitably supported horizontally in such a way that they may be caused to vibrate; sand sprinkled on them then forms figures in accordance with the manner in which the plates are vibrating. The authors have studied the relationships between the composition, constitution, &c., of the plates and the forms of the figures.

F. T. Sisco, *The Constitution of Steel and Cast Iron.—Part I.* (Transactions of the American Society for Steel Treating, June 1926, vol. 9, pp. 938–953). The author discusses in an elementary way some of the fundamental concepts necessary to a complete understanding of the constitution and structural changes of the alloys of iron and carbon. Simple crystallisation, saturation and equilibrium, crystallisation of metals, orientation and cleavage, crystal structure, amorphous solids, and allotropy of iron, are dealt with.

F. T. Sisco, *The Constitution of Steel and Cast Iron.—Part II.* (Transactions of the American Society for Steel Treating, July 1926, vol. 10, pp. 109–118). This paper discusses the determination of the critical points in metals and alloys and the methods of plotting cooling curves. The construction and interpretation of constitutional diagrams are also dealt with.

F. T. Sisco, *The Constitution of Steel and Cast Iron.—Part III.* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 267–284). The author discusses the solidification of binary alloys. The properties of eutectics and solid solutions are described and their structure illustrated.

F. T. Sisco, *The Constitution of Steel and Cast Iron.—Part IV.* (Transactions of the American Society for Steel Treating, Sept. 1926, vol. 10, pp. 457–475). A discussion of the critical points of low and medium carbon steels. The constitution of these steels is described according to the iron-carbon diagram. Photomicrographs of typical structures are included.

K. Schönert, *The Iron-Oxygen System* (Zeitschrift für anorganische Chemie, 1926, vol. 154, pp. 220–225). It is shown that the solubilities of oxygen, as ferrous oxide, in α-, β-, and γ-iron are probably 0·03, 0·13, and 0·15 per cent. respectively, and that it increases in γ-iron as the temperature rises. The solubility is 0·21 per cent. at the fusion point of molten iron, which is depressed to 1509°. By the addition of more oxygen two solid phases are formed, the oxygen-rich phase containing about 21 per cent. of oxygen and consisting of ferrous oxide with a small quantity of ferric oxide and 0·99 per cent. of free iron. These data are applied to the construction of the equilibrium diagram.

E. Zingg, *Diffusion of Carbon in α-Iron* (Stahl und Eisen, June 10, 1926, vol. 46, pp. 776–777). The object of the research was to obtain evidence as to whether carbon could actually be absorbed at temperatures below Ac3 or Ac2. The cementation medium employed was a mixture of hydrogen, hydro-carbons, and carbon monoxide from illuminating gas, prepared by purifying the component gases of all carbon dioxide, vapour, sulphuretted hydrogen, ammonia and other nitrogen compounds. The materials were a Swedish iron cold-rolled and recrystallised in a current of hydrogen at 600° C., and a rolled steel with carbon 1·2, silicon 0·23, and manganese 0·27 per cent. The Swedish iron specimens were 60 × 10 × 0·1 millimetres, and the steel specimen cut from the rolled bar was 60 × 10 × 1 millimetres. A second test was made with Swedish iron specimens treated in the same manner as the first, but with a thickness of 0·05 millimetre. These were heated in a nichrome-wound furnace with a porcelain tube. The first heat, lasting twenty hours, was at a temperature between 780° and 800°, and the second, lasting sixty hours, was between 670° and 690°. At the end of the heats the porcelain tube, with the specimen, was withdrawn from the furnace and allowed to cool in the air, the gas meanwhile continuing to be circulated. A microscopic examination of all

the specimens showed that in a range of temperatures from 650° up to 800° the outer zone had changed into a layer of cementite. In the α-range the boundary of this layer was sharply defined against the ferrite grains. In the experiment with the very thin sheets these were almost entirely transformed into cementite after heating at 670° to 690° for a sufficiently long period. In fact pure cementite may be produced in this way.

K. Honda, *The A2 Line in the Equilibrium Diagram of the Iron-Carbon System* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 247–250; *see also* Journal of the Iron and Steel Institute, 1925, No. II. pp. 345–348).

T. Ishiwara, T. Yonekura, and T. Ishigaki, *On the Ternary Diagram of the System Iron, Carbon, and Copper* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 81–114). The authors have investigated the equilibrium diagrams of the systems cementite-copper and iron-cementite-copper, and the following equilibria are dealt with: (1) Peritectic equilibrium of pseudo-binary form; (2) invariant equilibrium consisting of two liquid and two solid phases; (3) ternary peritectic equilibrium; and (4) ternary eutectoid. The portion of the ternary diagram representing the state of the alloys containing less than 30 per cent. of copper was determined, and a microscopic investigation was made of the binary and ternary eutectoid structures.

K. Honda, *Is the Direct Change from Austenite to Troostite Theoretically Possible?* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 417).

G. Takahashi, *The Equilibrium between Austenite and the Carbon Oxides* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 157–175). The author has studied the effect of temperature and composition of the gaseous phase on the carbon content in austenite, in equilibrium under one atmospheric pressure. The apparatus and methods used are described, and the results are discussed in detail. As the temperature rises the C content of austenite, existing in equilibrium with a mixture of CO and CO_2, decreases. The CO concentration of the gas in equilibrium with austenite of the same carbon content, or with austenite and free cementite, increases with rise of temperature. At a given temperature, the C content in austenite, existing in equilibrium with the gas mixture, increases as the CO concentration increases till free cementite appears. As the temperature rises the C content of austenite in equilibrium with ferrous oxides decreases; and the CO concentration in the gas in equilibrium with austenite and alpha-iron decreases, while that in equilibrium with austenite and ferrous oxide increases. The A1 transformation point was determined to be 726° C. by means of cementation in CO. Cementation is not produced by a gas mixture, the CO concentration of which is less than that with which austenite and alpha-iron or ferrous oxide are in equilibrium.

H. L. Maxwell and A. Hayes, *Solubility in Austenite of Carbon*

from Carbon and of Carbon from Iron Carbide (Proceedings of the Iowa Academy of Science, 1924, vol. 31, p. 284).

G. H. Brodie, W. H. Jennings, and A. Hayes, *Heat of Formation of Cementite as Electrolysed from a Pure Iron-Carbon Alloy of Eutectoid Structure and Composition* (Transactions of the American Society for Steel Treating, Oct. 1926, vol. 10, pp. 615–629). The paper gives the results of calorimetric determinations of the heat of formation of iron carbide. A value of − 13,580 calories per gramme molecule was obtained at 86° F. (30° C.). This is in essential agreement with the results of an independent investigation carried out by H. L. Maxwell in the same laboratory at a temperature of 1202° F. (650° C.). The agreement between the results obtained and those of Ruff are well within the experimental error. As a result of this investigation the results of Campbell and those of Schenck are considered inaccurate.

T. Ishigaki, *Determination of the Density of Cementite* (Kinzoku no Kenku, 1926, No. 3, p. 169). The author has determined the density of cementite by measuring steels of different carbon contents, by applying suitable factors for other impurities than carbon, and by extrapolating to the concentration of cementite. The result was 7657 at 4° C.

W. L. Fink and E. D. Campbell, *Influence of Heat Treatment and Carbon Content on the Structure of Pure Iron-Carbon Alloys* (Transactions of the American Society for Steel Treating, May 1926, vol. 9, pp. 717–754, 780). The principal object of the investigation was to determine the effect of carbon content and heat treatment on the space lattice of alpha-iron in pure iron-carbon alloys. X-ray patterns were obtained from a series of alloys varying in carbon content only. The results obtained were also correlated with the microstructure. The paper opens with an historical review of the work of previous investigators on crystal structure, and the X-ray methods and apparatus used in the present investigation are described. The changes in the alpha-iron lattice, the presence of gamma-iron lines, the changes in the gamma-iron lattice, and the presence of carbide lines were all observed. A body-centred, tetragonal structure, not previously observed, was found in eutectoid and hypereutectoid steels on water-quenching. The paper terminates with an excellent bibliography of literature on the crystal structure of metals.

R. Ruer, *Detection of the Thermal Effect in the Iron-Carbon Eutectoid* (Stahl und Eisen, July 8, 1926, vol. 46, pp. 918–920). The author traverses the results of the investigation by Hayes, Flanders, and Moore (Transactions of American Society of Steel Treating, 1924, vol. 5, pp. 183–194 ; Journal of the Iron and Steel Institute, 1924, No. I. p. 618), and shows that, notwithstanding their statement that Ruer's determination of the iron-carbon eutectoid point is open to question, their results really completely confirm those of his investigation made in 1921. He had then detected the stable eutectoid ferrite-graphite, corresponding with the pearlite, and whose temperature of equilibrium

with austenite he had determined as being 721° ± 3° to 733° ± 3°. The difference between the absolute values of these equilibrium temperatures and those obtained by Hayes and his associates is due to the fact that they used impure materials, whereas Ruer's were pure.

A. I. Brodskii, *Critical Points and Heat Capacities of Pure Iron* (Journal of the Russian Metallurgical Society, 1926, No. 1, Section 1, pp. 7–22).

H. Masumoto, *On the Equilibrium Diagrams of Cobalt-Nickel and Cobalt-Iron* (Kinzoku no Kenku, 1926, vol. 2, No. 10, pp. 1023–1038).

R. Hughes, *Thermal Treatment of Electrolytic Iron* in Vacuo *with Recovery of the Gases* (Revue de Métallurgie, Mémoires, Dec. 1925, vol. 22, pp. 764–775). The author has studied the effect of dissolved gases in electro-deposited iron. By means of specially designed apparatus the volumes of gases evolved in different times and at different temperatures were measured, and samples of the material, from which the gas had been removed in greater or less degree, were subjected to various mechanical tests. The gases were found to consist mainly of hydrogen and carbon monoxide, and very small quantities of lead were found to have distilled from the metal, though the source of this element is not suggested. At any given temperature the gases were evolved increasingly rapidly for the first few minutes, and then less rapidly, the curve showing the volume-time relationship tending to rise asymptotically to a horizontal line. The volume-temperature relationship was linear up to 900° C.; above that temperature the increase in gas liberation became less and the maximum evolution appeared to occur at 1500° C. Magnetic and mechanical properties showed some improvement, which the author attributes to the evolution of the gases; the magnetic variations appeared to depend only on the elimination of the gas, whereas the mechanical properties were dependent both on the removal of the gas and on the crystallisation which occurred. The possible existence of a compound of iron and hydrogen, previously suggested by the author in collaboration with R. Cazaud, is further discussed. (*See* Journal of the Iron and Steel Institute, 1925, No. II. p. 516.)

Gases in Electrolytic Iron and their Effect on its Properties (Metallurgist, Apr. 30, 1926, pp. 53, 54). An abstract in English of the above paper by R. Hughes.

S. Umino, *On the Specific Heat of Carbon Steels* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 331–369). The heat content of carbon steel at high temperatures was determined by the method of mixtures. Twelve steels were used in the investigation with carbon ranging from 0·09 to 2·84 per cent., and the range of temperature used was 23° to 1250° C. According to the author, the specific heat is only constant above the A3 point, and below this point it increases with the rise of temperature. The quantity of heat for the dissolution of pearlite in iron was determined by measuring the heat content above and below the A1 point. This heat increases proportion-

ally with the carbon content, reaches a maximum at 0·9 per cent. carbon, and ends at 6·7 per cent. For the dissolution of 1 gramme of carbon in iron 1760 calories are required, while 16·1 calories are required for the dissolution of 1 gramme of pearlite in iron. The mean specific heat of cementite increases with a rise of temperature; it is 0·149 at 150° C. and 0·220 at 850° C. The heat of transformation from martensite to pearlite was found to be proportional to the carbon content. The heat of transformation from austenite to martensite, and that from martensite to pearlite, increase proportionally with the content of eutectoid carbon. The heat of transformation from austenite to martensite for a eutectoid steel amounts to 5·9 calories.

M. Kawakami, *On the Specific Heat of Iron-Nickel Alloys* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 251–262). Alloys of various compositions of iron and nickel were subjected to the following heat treatments: (1) Annealed at 900°, (2) annealed and cooled in liquid air, (3) quenched in water from 1000°, and their mean specific heat between 300° and 30° was measured. The specific heat has slightly different values for different structures. Thus the specific heat of martensite is less than that of nickel-ferrite, and the latter is greater than that of austenite.

G. Moressée, *The Heat of Fusion of Metals* (Revue Universelle des Mines, July 1, 1926, vol. 11, pp. 6–9). The latent heat of fusion of metals is discussed thermo-dynamically, and an equation expressing it in terms of the absolute melting point and the atomic weight of the particular metal is derived. A comparison of the calculated values with some obtained experimentally shows fair agreement, all except one of the calculated figures being higher than the corresponding experimental determination. The author explains this divergence as being due to the fact that the specific heat of any metal is not the same at all temperatures. The author's expression for the latent heat of fusion, $3\frac{T_f}{P_a}$, where T_f is the absolute temperature of the melting point and P_a is the atomic weight of the metal, can be applied in cases where the experimental difficulties are too great, as, for instance, in the case of carbon.

C. Benedicks, H. Bäckström, and P. Sederholm, *Anomalies in Heat Conduction, with Some Determinations of Thermal Conductivity in Iron and Carbon Steels* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 127).

G. Moressée, *The Cooling and Heating of Metals by Radiation* (Revue Universelle des Mines, Aug. 15, 1926, vol. 11, pp. 175–186). The laws governing the heating and cooling of metals by radiation are treated mathematically.

L. B. Pfeil, *The Effect of Occluded Hydrogen on the Tensile Strength of Iron* (Proceedings of the Royal Society, 1926, vol. 112, (A), pp. 182–195). Tests were carried out in which the electrolytic pickling of the test-pieces was caused to continue even during the actual

mechanical testing of the specimen. This precaution was taken because it is known that iron and steel, embrittled by occluded hydrogen, will recover itself on being allowed to stand. The remarkable weakening effect of occluded hydrogen on the intercrystalline boundaries was demonstrated. The ratio between the tensile strength as normally measured and the boundary strength as found by these tests was shown to vary with the size of the crystals in the test-pieces. The hydrogen also affected the cohesion across the cubic cleavage planes, but did not seriously affect the resistance to movement along the slip-planes. In single iron crystals the surface cold-working during machining, which damages certain crystallographic planes, has no effect on the tensile results, but becomes very evident during these pickling tests. The effect of hydrogen on finely crystalline iron is not so marked at temperatures a little above room temperature. Unless the pickling were continued during the stressing the effect of the hydrogen was scarcely noticeable, showing that ordinary tensile tests are of only limited value as a means of investigating failures supposedly due to occluded hydrogen.

T. C. Sutton and H. R. Ambler, *Abnormal Absorption of Gases by Steel* (Paper read before the Faraday Society, Oct. 27, 1926). The authors have investigated the absorption of gases by steel, subjected to high pressures and temperatures. It was found that steel absorbs as much as 30 cubic centimetres of gas per gramme, or many times as much as is absorbed under the conditions hitherto recorded. The gases so absorbed are retained firmly by the steel at temperatures below 600° C. Even on prolonged exhaustion at about 1000° C. desorption is not complete. The absorption of 1 cubic centimetre of mixed gases is accompanied by an energy evolution of about three-quarters of a gramme-calorie.

H. S. Rawdon, P. Hidnert, and W. A. Tucker, *Some Effects of Hydrogen on Iron and their Bearing on a Reported Transformation at* 370° C. (698° F.) (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 233–256). The authors have investigated the results obtained by Sirovich (Gaz. chim. Italiana, 1923, vol. 53, pp. 674–688) on a transformation in iron at 370° C. The results of the investigation do not confirm the conclusions of Sirovich as to a polymorphic transformation in iron at this temperature, although they indicate an "irregularity" in the behaviour of iron when heated at about this temperature. This irregularity is shown by thermal analysis to appear as an evolution of heat upon heating which reaches its maximum at about 300° C. This was more pronounced in specimens that had been heated in hydrogen. An irregularity in thermal expansion around 370° C. was likewise detected in similarly treated specimens. Iron containing an appreciable amount of iron oxide showed this phenomenon best. Iron charged with "cathodic" hydrogen behaved irregularly on heating, but showed an absorption of heat. A possible explanation suggested for the heat evolution in

the neighbourhood of 370° C. occasionally observed during the heating of iron is the recrystallation of very fine-grained metal, such as might result on reduction of iron oxide by hydrogen.

K. Iwasé, *Occlusion of Gases by Metals and Alloys in Liquid and Solid Phases* (Kinzoku no Kenku, 1926, No. 3, p. 119). The author has determined the quantity of different gases which can be absorbed or evolved by metals at high temperatures without causing any chemical reactions.

Magnetic Properties of Iron and Steel.—*Report of Committee A6 on Magnetic Properties* (American Society for Testing Materials, June 1926). A revision is submitted of the standard methods of test for magnetic properties of iron and steel which will make clearer the distinction between commercial test methods and absolute methods used for checking the accuracy of the permeameter.

Y. Kidani and R. Sasaki, *On the Change of Temperature and Magnetic Induction of Steel in Tension and Compression Test* (Proceedings of the Imperial Academy, May 1926, vol. 2, No. 5, pp. 212–213). Experiments were carried out to observe the heat evolution or absorption and change of magnetic induction lines of initially magnetised or demagnetised carbon steel when they undergo elastic or plastic deformation. There occurs a minimum point of temperature in the tension test, and a noticeable point of change of temperature slope in the compression test during the transition from the elastic to the plastic state. In the results of the tension test, the magnetic induction lines are increased in the elastic state due to the earth's magnetic field, which is the reverse in the case of the compression test. In both the tension and compression tests, the magnetic induction lines are decreased in the plastic state. There is no appreciable change of magnetic induction during the compression of a test-piece having no initial permanent magnetism.

R. L. Sanford, *Non-Destructive Testing of Wire Hoisting Rope by Magnetic Analysis* (United States Bureau of Standards, 1926, Technologic Paper No. 315). The paper presents the results of an investigation of the possibilities of magnetic analysis as a reliable method for the testing of wire rope. The investigation was of a fundamental nature, and consisted in a study of the magnetic properties of steel wire and the effect on them of deterioration due to various causes. The effects of stress, wear, and fatigue were studied. Mechanical stress exerts a marked influence upon the magnetic properties of steel. The effect is more pronounced in the lower part of the magnetisation curve, and to it may be attributed much of the difficulty heretofore experienced in the attempt to discover definite relationships between the magnetic and mechanical properties of steel. The reluctivity relationship is useful for indicating something of the homogeneity of a specimen across the section. If the reluctivity plotted against the magnetising force is a straight line, then the material is magnetically pure and homogeneous.

The effect of wear is to reduce the cross-sectional area, which results in a modification of the magnetic properties. Experimental evidence so far obtained indicates that the near approach to failure by fatigue is not accompanied by a corresponding change in magnetic properties. As a research method for use in the study of the properties of wire rope and other materials, magnetic analysis has undoubted value. There are as yet so many sources of uncertainty, however, that there seems to be no immediate prospect of the development of a magnetic method for the inspection of wire rope of a sufficient degree of reliability to warrant its use on a commercial basis.

H. Styri, *Testing of Ball-Bearing Races by Electric and Magnetic Methods* (Paper read before the American Society for Testing Materials, June 1926). The paper describes a simple method developed to compare the magnetic qualities and hardness of ball-bearing races by one reading, involving the use of a phase shifter. The investigation covers a number of different sizes as well as different heat treatments of the races.

T. Spooner, *The Magnetic Analysis of High-Speed Steel* (Paper read before the American Society for Testing Materials, June 1926). The author presents the results of an investigation to determine the relation between the electrical and magnetic properties and heat treatment of high-speed steel, with the object of devising a simple method of inspection for heat-treatment control. Various methods of tests are discussed. The most suitable ones involve an alternating-current magnetic test at fairly high magnetising forces. Such a test gives a quick and reliable indication of the uniformity and absolute values of the heat-treating temperatures, disclosing differences which are not brought out by the usual methods. If quenching temperatures are known, the actual drawing temperature can be quite accurately determined magnetically.

F. V. Lindsey, *Electrical Resistance Materials* (Fuels and Furnaces, Feb. 1926, vol. 4, pp. 223–224). The qualifications of a satisfactory electrical resistance material include strength, toughness, and ductility, and it should be impervious to corrosive influences. Of the most suitable metals, chromium in combination with nickel produces a very strong, hard alloy, but also has a tendency to be brittle.

J. R. Adams and F. E. Goeckler, *Some Factors affecting Coercive Force and Residual Induction of Some Magnet Steels* (Transactions of the American Society for Steel Treating, Aug. 1926, vol. 10, pp. 173–194, 213). The factors that have the greatest influence on coercive force and residual induction are: composition, melting, casting, rolling or forging, and heat treatment. Each of these factors is dealt with, and a number of tables are included which show their effects on magnet steel.

H. Tscherning, *Permax, a New Ferro-Nickel having Remarkable Magnetic Properties—Comparison with Permalloy* (Journal de Physique et le Radium, 1925, vol. 6, pp. 300–304). A comparison was made of the magnetic properties of a new iron-nickel alloy, Permax, with those of

Permalloy, by the fluxmeter method. Permax was found to have a very low hysteresis at high fields, but high hysteresis at low fields. The permeability is high for a field of 1 gauss, and at higher fields the permeability is moderate. At low fields there is a very marked "magnetic viscosity."

A. Eucken, *What is a Metal?* (Zeitschrift für Metallkunde, June 1926, vol. 18, pp. 182–188). The properties of metals have certain apparent relationships which up till now have not been sufficiently investigated. Of these, electric conduction as the basis of metallic properties seems to be the most easily dealt with, and a brief review of its conformity to laws is made. The ability of metals to conduct electricity is explained by the presence of free electrons; the fact that not all elements, but only a certain number, have free electrons is in best accord with the new theories of the structure of the atom.

T. Spooner, *The Properties and Testing of Magnetic Materials: Effect of Temperature* (Electric Journal, 1926, vol. 23, pp. 79–83).

Corrosion and Prevention of Corrosion.—*Report of Committee A5 on Corrosion of Iron and Steel* (Presented to the American Society for Testing Materials, June 1926). The Committee submit the results of accelerated tests on sheets coated by several zinc-coating processes and by lead spraying, and of an inspection of copper-bearing and non-copper-bearing materials exposed to the atmosphere and to total immersion. New tentative specifications for the coating on zinc-coated wire, for galvanised telephone and telegraph line wire, and for galvanised tie wire are also submitted.

The Deterioration of Structures in Sea-Water. Sixth (Interim) Report (Department of Scientific and Industrial Research. London, 1926: H.M. Stationery Office). This publication contains, among others, the following reports: *Summary of Reports received from Correspondents relating to the Periodical Examination of Iron and Steel Specimens at Colombo, Halifax, Plymouth, and Auckland.* Prepared by P. M. Crosthwaite. *Report on the Condition of the Painted Plates exposed at Southampton.* By F. E. Wentworth-Sheilds. *Report of the Work Carried out for the Committee during the Year* 1924–25. By J. Newton Friend.

W. Palmær, *Theory of and Investigation into the Corrosion of Metals* (Korrosion und Metallschutz, 1926, vol. 2, pp. 3–8, 33–38, 57–62). The speed of dissolution of metals in acids and in salt solutions depends upon the difference in potential, the conductivity of the solution, and the resistance capacity of the local cells. To account for the fact that a pure and homogeneous metal will resist acid, the author puts forward the theory that a metastable condition is set up in which the whole of the surface has the same potential against the solution and, therefore, no electrolytic action can take place. Carbon dioxide alone has no appreciable action on the rate of rusting of iron, but atmospheric oxygen acts as a depolariser and assists the action of the carbon dioxide.

The prevailing factor in the rusting of iron appears to be the electrical conductivity of the liquid film on the iron.

M. G. Delbart, *Comparative Study of the Corrosion of Irons in Sulphuric Acid of Various Concentrations* (Comptes Rendus, Nov. 23, 1925, vol. 181, pp. 786–788). The concentrations were all greater than 1·6 per cent. total SO_3. Starting with this concentration, the irons rich in phosphorus, silicon, and manganese were all more corroded than purer irons, malleable white irons giving the lowest figures. The difference in corrodibility between the grey irons and steels was very great, mild steel being very much better than the other metals. The same applies to corrosion in solutions containing 80 per cent. total SO_3. In oleum containing 85 per cent. SO_3 the impure grey irons, except a manganese grey iron, were more corrodible, and the purer irons less so; fifteen out of twenty-six irons tested gave figures lower than the lowest obtained with steels. The conclusion is drawn that for most corrosion-resisting purposes steel is to be preferred.

R. Girard, *Researches on the Corrosion and Rusting of Steel and Cast Iron* (Revue de Métallurgie, Mémoires, 1926, vol. 23; June, pp. 361–367; July, pp. 407–417). Experiments were made to compare the relative behaviours of steel and cast iron when corroded by dilute acids and salts. They showed that towards very dilute acids the metals reacted in very similar manners; "weak" acids showed remarkable powers of attack. The importance of the skin of hydrate formed, which determines the extent of the corrosion, is stressed. Corrosion experiments carried out with more concentrated acids are condemned as useless and meaningless, as their results cannot be applied to the case of dilute acids. The experiments carried out in salt solutions demonstrated the importance of aeration on the rusting and corrosion of steel and cast iron. In the absence of oxygen the two metals are attacked in a similar manner and to similar extents; but in the presence of oxygen the steel is attacked locally and is pitted deeply, showing considerable sensitivity to the degree of aeration and the ferric products being only slightly adherent, while cast iron is uniformly covered with compounds which are, relatively, protectors. This difference of adhesion is certainly due to the heterogeneous structure of cast iron.

P. D. Schenck, *Corrosion Theories and Facts* (Chemical and Metallurgical Engineering, June 1926, vol. 33, pp. 357, 358). The author calls for more precise information on the conditions under which corrosion tests are made. He also objects to the practice of attempting to forecast the behaviour of acid-resisting alloys from laboratory test results; these, he says, can bear no true relation to the performance of the alloys under service conditions, owing to the fact that the conditions in service and under test are not identical.

E. L. Rhead, *Ferrous Metals and Corrosion* (Journal of the Municipal College of Technology, Manchester, 1926, vol. 12, pp. 41–53). A discussion of the corrodibility of cast iron, wrought iron, and steel. The effect of the complex character of cast iron and its corrodibility is

often underestimated. The physical characters of its components differ widely; their coefficients of thermal expansion at different temperatures vary so that, in cooling down and in subsequent variations of temperature to which the metal may be subject in use, cavities and interstices may be produced, which enable the corrosive liquids and gases to find access to the interior of the metal. The larger the amount and the coarser the character of graphite present in the cast iron the more rapidly it corrodes. For many chemical vessels it is necessary to make grey iron castings, in which the graphite flakes should be as small as possible, and the actual amount as low as possible. The experience of the author has confirmed the opinion that the best qualities of wrought iron are superior to mild steel under similar conditions. With regard to high-silicon iron the best protective results are obtained with a silicon content of 13 to 18 per cent. The author, with others, carried out an investigation to ascertain the effects of silicon on the structure and constituents of the material. They found that when the silicon content reached 16 to 17 per cent. the compound Fe_2Si separated as a constituent of the material. The separation of free Fe_2Si begins at 17·1 per cent. silicon, and so long as the silicide remained in solid solution its effect increased till the saturation point was reached, but until a sufficient amount was produced and present no protective effect was secured. Much of the silicon iron when first put into service shows considerable effervescence and subsequent corrosion, often with marked pitting, which is due to the behaviour of the molten metal during solidification. When the hot metal comes into contact with the cold surface of the mould the effect is to freeze out the constituent with the higher melting point, and consequently more readily solidified, with the result that a layer of more or less pure iron, deficient in silicon, and therefore non-resistant, forms at the mould face.

A. V. Blom, *Protection of Iron against Corrosion by Lead* (Zeitschrift für angewandte Chemie, 1926, vol. 39, pp. 555–556).

E. S. Hedges, *Liquid-Line Corrosion* (Journal of the Chemical Society, Apr. 1926, pp. 831–833). Experiments are described which indicate that the extra solution of a solid by a liquid at the "water-line" is due to an enhanced reactivity of the solvent at the surface Non-metallic as well as metallic materials were used, and as some of the former were non-conductors, the author considers that the theory of electrolytic action is ruled out; also, as arrangements were made for the supernatant atmosphere to consist of hydrogen, or for the solution itself to be more strongly oxidising than air, he considers that the oxygen-depolarisation theory is not applicable either. By adjusting the rate of solution of zinc or magnesium in dilute acids so that the gas bubbles coalesced to form a large bubble at the surface, a roughly circular patch showing strong preferential corrosion was obtained in the region adjacent to the bubble. It was found that the effect on the metal varied according to whether gas bubbles formed, washing

the solution upwards, or whether little or no gas was formed and the reaction products flowed down the surface. In the former cases the metal was of uniform thickness and appeared to be "cut" at the water-line; in the latter cases the metal was progressively thinned from the bottom to the water-line, resembling a fine wedge. Iron showed very little extra corrosion at the surface of the liquid when immersed in hydrochloric acid, but when a mixture of hydrochloric and nitric acids was used the effect was very marked.

F. N. Speller, *The Problem of Steam-Boiler Corrosion* (Mechanical Engineering, Oct. 1926, vol. 48, pp. 1017–1023). The mechanism of corrosion is briefly indicated, and the effects due to the composition of the feed-water, such as the presence of dissolved oxygen, carbon dioxide, salt, alkali and acid, are discussed. The influence of scale, organic matter, and the composition of the materials of construction of the boiler itself, are dealt with. Preventive measures are described, and notes on general precautions to be taken for the care of boilers are added.

R. Stumper, *Corrosion Phenomena Observed on Boiler Parts* (Feuerungstechnik, Mar. 1, 1926, vol. 14, pp. 121–123). The corrosion of copper covers screwed on to the cast-iron walls of superheaters was found to be due to the combined action of steam, condensed water, and waste gases. The products of corrosion were basic copper sulphate and iron sulphate, the covers being attacked first and the walls later. Covers made of iron having the same coefficient of dilatation as the wall material could be used equally well, and would lessen the corrosion.

W. M. Barr and R. W. Savidge, *Boiler Corrosion and Possible Combative Measures* (Paper read before the American Institute of Chemical Engineers, June 21–24, 1926: Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, pp. 607, 608). The authors studied the effects of strain in the metal, and the presence of scale-forming substances, dissolved oxygen, and causticity, their work having special reference to locomotive practice.

S. W. Parr and F. G. Straub, *The Cause and Prevention of Embrittlement of Boiler Plate* (Paper read before the American Society for Testing Materials, June 1926: Chemical and Metallurgical Engineering, Oct. 1926, vol. 33, pp. 604–607). Three types of cracks are recognised, due to (1) direct corrosion, (2) fatigue, and (3) caustic solutions. Each is found to be distinctive in type, and the authors discuss their characteristics. A method was devised whereby the embrittlement effect could be produced at will, thus making it possible to study the conditions under which it occurs, and remedies for its prevention. The results indicate that two conditions must be present simultaneously to produce the embrittlement effect: first, the stressing of the metal above the yield point; and, second, the concentration of sodium hydroxide to a point which is in excess of 350 grammes per litre. Parallel tests omitting the sodium hydroxide show no effect. The

modification or control of the chemical condition of the water has been found to be effective in preventing embrittlement. Results on actual plants show that by maintaining a ratio of sodium sulphate to sodium hydroxide in excess of 2 no embrittlement is found to occur. Free sodium carbonate in the water is in itself not active in producing embrittlement, but contains a potential danger in that it is gradually hydrolised into the caustic form. The same report is published elsewhere (Illinois University, Engineering Station, 1926, Bulletin No. 155).

U. R. Evans, *Oxidation, Passivity, and Corrosion* (Lecture at the Royal Institute, May 20 and 27, 1926: Nature, July 10, 1926, vol. 118, pp. 51–53). Some experiments are described showing the changes produced by oxygen in the chemical behaviour of electrolytic iron. It is well known that solutions of oxidising agents such as chromates render iron passive towards copper salts. In the case of electrolytic iron dissolved oxygen can also bring about this passivity. If a disc of mild steel is whirled in distilled water containing oxygen it attains a yellow appearance, due to the adherence of ferric hydroxide over the surface. If taken out after 100 minutes, dried and tested with copper nitrate, the iron will blacken within a few seconds. On repeating the experiment with electrolytic iron, however, it develops rust only in minute spots, which probably represent the site of pores in the metal into which oxygen cannot rapidly penetrate. After 100 minutes whirling the iron is found to be quite passive towards copper nitrate.

L. McCulloch, *Passivity and Corrosion of Iron* (Paper read before the American Electrochemical Society, Oct. 1926). Two new instances of passivity in iron are described. Very small particles of electrolytic iron have been found not to rust as does ordinary iron. In a solution of ammonia and ammonium chloride, iron was found either to be corroded rapidly or else to be passive. The progressive rusting of iron is ascribed to the catalytic action of soluble iron salts, which are held upon the iron surface by the coating of rust. These soluble iron salts are a product of the electrolytic action, which takes place over the surface of the metal when exposed to natural waters and air. Thus the modern electrolytic theory and the old acid theory are combined into one, but the carbon dioxide to which the corrosion was attributed by the acid theory is no longer necessary, since iron salts of stronger acids are seen to be present.

U. R. Evans, *The Fundamental Principles of Corrosion* (Metal Industry, 1926, vol. 29; Aug. 6, pp. 130–132; Aug. 13, p. 152).

W. G. Whitman, *Corrosion of Iron* (Chemical Review, 1926, vol. 2, pp. 421–435). The modern electrochemical theory of corrosion of iron is reviewed.

C. Benedicks and R. Sundberg, *Electrochemical Potentials of Carbon and Chromium Steels* (Paper read before the Iron and Steel Institute, Aug. 1926: this Journal, p. 177).

T. Fujihara, *Testing Corrosion of Iron* (Chemical and Metallurgical

Engineering, June 1926, vol. 33, p. 346). The author has made corrosion tests with a solution containing equal parts of distilled water and ethyl alcohol. This solution enabled him to differentiate between specimens of iron with regard to their purity.

V. A. Kistyakovskii, *The Rusting of Iron* (Zeitschrift für Elektrochemie, 1925, vol. 31, pp. 625–631).

Corrosion, Tarnishing, and Tinting of Metals (Engineering, June 4, 1926, vol. 121, p. 667). A brief account of two lectures given by U. R. Evans before the Royal Institution in May 1926.

E. C. Dickinson, *Corrosion of Cast Iron* (Bulletin of the British Cast Iron Research Association, Oct. 1926, No. 14, pp. 14–16).

Protection of Steel by Coating.—M. R. Thompson, *Acid Zinc-Plating Baths* (Paper read before the American Electrochemical Society, Oct. 1926). The author has studied the possibilities of acid zinc-plating baths used in electro-galvanising. It was not found possible to increase materially their throwing power, chiefly because of the low cathode polarisation which they possess. It was found, however, that simple baths of much higher conductivity than those commonly used may be prepared, in which satisfactory deposits can be produced at unusually high-current densities. Such baths may contain a moderate concentration of zinc chloride (*e.g.* 2-N); a high concentration, *e.g.* 3 to 4-N, of sodium or ammonium chloride, and a small concentration, *e.g.* 0·25-N, of aluminium chloride. These baths operate best at a pH from 3·5 to 4·5.

F. X. Mettenet, *Gas-Fired Galvanising Kettle* (Forging, Stamping, Heat Treating, May 1926, vol. 12, p. 184). The kettle is 25 feet 4 inches long, 1 foot 10 inches wide, and 2 feet 10 inches deep; it holds over 20 tons of spelter. Forty-two gas-burners are spaced equally along each side; the fuel is projected into a bed of refractory material, which equalises the distribution of heat and prevents spot burning. Atmospheric air is used in the burners, no air-compressor being needed; the gas pressure varies from 2 to 10 lbs. per square inch. Advantages in every direction have been gained by the introduction of gas as the heating agent.

W. H. Finkeldey, *Microstructure of Zinc Coatings* (Paper read before the American Society for Testing Materials, June 1926).

Marnach, *The Tinning of Grey Iron Castings* (Die Giesserei, Sept. 11, 1926, vol. 13, p. 691). The tinning of iron castings is attended with some difficulty, on account of the presence of graphite, and there is therefore no metallically pure surface for the tin to adhere to. The castings must first be coated with another metal, copper being generally used. The electrolytic method of coating can be adopted, but this is costly, and a cheaper way is to dip the casting in an acid copper bath, which gives an adherent copper coating in a few seconds. The castings must first be sand-blasted and then pickled. Dipping in the tin bath should follow immediately after removal from the copper

bath. If this is not practicable, the copper-coated castings should be stored meanwhile under water to prevent oxidation.

C. H. Humphries, *Plating with Chromium for Wear* (Iron Age, Sept. 2, 1926, vol. 118, pp. 599–600). The author outlines a number of applications of chromium-plating. The use of chromium coating for rubber tire moulds has been particularly advantageous. Until recently, soap solution or soapstone was necessary to prevent the tires from sticking to the moulds, but the adoption of chromium-plated moulds has eliminated the use of soapstone, and effected a considerable saving in mould maintenance costs.

Plating Steel Auto Parts with Chromium (Iron Trade Review, May 6, 1926, vol. 78, pp. 1182–1183). Particulars are given of the methods adopted by an American concern for the plating of automobile radiators and other parts with chromium. The articles are first given a coating of copper, and then nickeled before the chromium is deposited. The solution used contains chromic acid, chromium sulphate, and boric acid.

Chromium-Plating (Iron Age, Apr. 29, 1926, vol. 117, pp. 1187–1189). A short illustrated description of the methods used at an American plant for the chromium-plating of various automobile parts. The sequence of operations is as follows: polishing, copper-plating, nickel-plating, buffing, chromium-plating. After the chromium-plating no further buffing is necessary.

Stellite Surfacing or "Stelliting" (Machinery, May 20, 1926, vol. 28, p. 174). A short notice of a paper by A. V. Harris read before the American Welding Society, describing a process for applying stellite to the surface of metal parts which have to withstand heat, abrasion, corrosion, or a combination of these. It can be done with the oxy-acetylene blowpipe or the electric carbon arc. The note is chiefly concerned with cases in which stelliting can be used with advantage.

Stelliting Metal Parts (Machinery, June 3, 1926, vol. 28, pp. 229–232). This article is an amplification of the note referred to above, and gives full details of the stelliting process.

C. M. Hoff, *Cadmium: its Electrodeposition for Rust-Proofing Purposes* (Paper read before the American Electrochemical Society, Oct. 1926). The physical and chemical properties of cadmium are described. It is indicated that cadmium should be a better corrosion preventative than zinc, because it is less active chemically, but at the same time protects iron electrochemically. It forms a protective oxide film, is not amphoteric in character, and although softer than zinc is more ductile. Thin deposits of cadmium effect comparatively great rust resistance, and the time of deposition is short. A solution has been developed which will deposit cadmium in a dense, ductile, adherent form over a wide range of current densities. It is in equilibrium with the anodes, is self-sustaining, and has low resistance and high throwing power.

W. E. Hughes, *Studies on Electro-Plating. VI.—Barrel-Plating* (Metal Industry, 1926, vol. 28; May 14, pp. 457–459; May 21,

pp. 475–477; May 28, pp. 497–498). *See* Journal of the Iron and Steel Institute, 1926, No. I. p. 667.

H. E. Haring, *A Simple Method for Measuring Polarisation and Resistivity* (Paper read before American Electrochemical Society, Apr. 1926: Metal Industry, May 7, 1926, vol. 28, pp. 435–437). A description of a device for measuring polarisation and resistivity in electroplating operations, requiring neither complicated apparatus nor special skill. A rectangular trough is fitted with parallel plane electrodes at its ends, composed of the metal under examination. Its length is divided equally by two parallel wire gauzes which behave as non-polarised electrodes. The potential drop across the middle compartment must then be entirely "IR" drop (I = current flowing, R = resistivity), and since the size of the middle compartment is exactly the same as those of the end compartments, any excess potential drop in the latter must be due to polarisation.

G. Fuseya and K. Murata, *The Common Properties of Addition Agents in Electrodeposition* (Paper read before the American Electrochemical Society, Oct. 1926). The authors review the various theories that have been advanced to account for the beneficial effect on the cathode resulting from the addition of glue and other substances to the electrolyte. Experiments made with copper sulphate and with silver nitrate baths are described, and the results obtained with a large variety of substances introduced into the electrolytes are tabulated.

R. L. Rolf, *The Elements of Good Pickling Practice* (Forging, Stamping, Heat Treating, July 1926, vol. 12, pp. 248–249, 254). The article is reprinted from U-loy News. The author discusses the various factors, such as composition, temperature, duration of the treatment, the use of inhibitors, agitation of the bath, &c., which enter into the practice of pickling. The construction of the vats is briefly described, and the proper ventilation of the pickling department and the care of the workmen is advocated. Pickling is indispensable in the drop-forge industry, as it reveals burns, seams, laps, and other forging defects which may not be observed when the work is cleaned by tumbling or sand-blasting.

B. T. Sweely, *Practical Chemical Control of Pickling-Room Solutions* (Journal of the American Ceramic Society, Sept. 1926, vol. 9, pp. 590–592). The paper gives a brief outline of pickling-room practice, and gives in detail a rapid method of titration of solutions by use of specially graduated cylinders and the addition of an indicator to normal or fractionally normal solutions.

J. E. Hansen and G. S. Lindsey, *Some Factors Influencing the Rate of Pickling of Sheet Iron* (Journal of the American Ceramic Society, Aug. 1926, vol. 9, pp. 481–492). An investigation of the various factors entering into the pickling of sheet iron shows that a freshly made sulphuric acid pickling bath pickles faster than a bath in which there is any concentration of ferrous sulphate. No advantage is obtained

by adding old pickling solution to a new bath. Increase of ferrous chloride in an 11·45 per cent. muriatic acid bath at 80°F. increases the rate of pickling, although this is contrary to theory. Ferric sulphate in the sulphuric acid bath will accelerate the rate of pickling, but will soon change to ferrous sulphate, and then retard the rate. Decrease in acidity from 6·54 to 4·6 per cent. sulphuric acid lowers the rate of pickling, and *vice versa*, but increase of pickling temperature accelerates the rate of pickling with sulphuric acid and will more than offset the weakening of the acid in commercial use. Iron annealed just previous to pickling loses 250 to 400 per cent. more in weight in pickling than unannealed iron. The use of a Monel metal basket accelerates the rate of pickling due to electrochemical reactions. Additions of muriatic acid or sodium chloride to a sulphuric acid pickling bath, other conditions remaining constant, retard the rate of pickling.

H. F. Staley, *The Theory of Cleaning of Sheet Iron and Steel for Enamelling Purposes* (Journal of the American Ceramic Society, Sept. 1926, vol. 9, pp. 593–597). Cleaning may be done by sand-blasting, heating, use of organic solvents, or use of alkaline solutions. Of these methods, heating and the use of alkaline solutions are important at present. In cleaning by heating the best results are obtained when the articles are first dipped in a solution of acid, heated uniformly to the lowest temperature that will cause the oils and greases to be burned off, and cooled slowly, both heating and cooling being done with the admission of as little air as possible. In cleaning by the use of alkaline solutions, saponifiable oils are removed by the formation of soaps and the subsequent solution of these; non-saponifiable oils are removed by emulsification. Efficient cleaning depends primarily on the choice of cutting and drawing oils, so as to have present a proper ratio of saponifiable and non-saponifiable oils. The cleaning solution must vary in composition according to the kinds and amounts of oils to be removed.

For Enamelling Metal (Iron Age, Sept. 9, 1926, vol. 118, p. 719). It is stated that a process has been developed by W. J. Beck and J. A. Aupperle for the production of sheets for enamelling. The chief feature is the production of an iron with a definite and uniform oxide constituent, which is believed to unite with the enamel in the baking process and to promote adherence. The open-hearth process is used; the temperature is kept high, and ore is added to the charge until a high degree of refinement has been obtained. The residual manganese is kept below 0·025 per cent.

I. S. Wishoski, *Japanning an Extreme Variety of Parts in Large Quantity* (Fuels and Furnaces, Feb. 1926, vol. 4, pp. 183–187). Illustrated particulars are given of the japanning department of the Motor Products Corporation, Detroit, Michigan. Details are also given of the method of applying a wood-grain finish on metal objects.

I. S. Wishoski, *Electric Ovens give Excellent Service in Baking Japan on Filing Cabinets* (Fuels and Furnaces, Mar. 1926, vol. 4,

pp. 299–302). The principal features of the construction and operation of the electrically heated conveyor japanning ovens in operation at the Tonawanda plant of the Kardex-Rand Co. are described.

I. S. Wishoski, *Chassis Frames Japanned very Economically in Conveyor Oven* (Fuels and Furnaces, May 1926, vol. 4, pp. 571–576). An illustrated description of the japanning plant of the Midland Steel Products Co., Detroit. Automobile chassis frames are automatically washed, rinsed, dried, japanned, and baked at the rate of about 240 frames per hour. Throughout the whole of the operations the frames are carried by a single continuous chain conveyor, thus entirely eliminating handling.

W. E. Crum, *Japanning Stove Parts in a Continuous Oven* (Fuels and Furnaces, July 1926, vol. 4, pp. 829–831). Particulars are given of a japanning oven of the double-oven type. Each tunnel is ventilated separately, and is provided with a conveyor driven by individual motors which gives independent control of conveyor speeds.

G. H. Fox, *Automobile Wheels Automatically Handled during Baking Operation* (Fuels and Furnaces, Sept. 1926, vol. 4, pp. 1087–1088). Particulars are given of the drying ovens in operation at the plant of the Detroit Sheet Metal Works, Detroit, Michigan. The ovens are of the continuous-conveyor tunnel type.

Enamelling and Glazing of Iron and Steel (Metal Industry, May 14, 1926, vol. 28, p. 460). A summary of the results of investigations made by the Bureau of Standards, Washington.

W. Mason, *The Manufacture of Enamels* (Metal Industry, 1926, vol. 28; June 4, pp. 525, 526; June 11, pp. 550, 551). The principles governing the manufacture of enamels are explained in detail, and the mixing and melting of the charges are described.

C. D. Wilkinson, *Gas Produces Better Results at Less Cost* (Journal of the American Ceramic Society, Oct. 1926, vol. 9, pp. 693–696). A comparison of gas- and coal-fired sheet iron enamel furnaces is given. Automatic control is possible with gas, and fewer furnace repairs, increase of production, and lower operating costs are attained with the use of this fuel.

Research Laboratories.—H. W. Gillett, *Government co-operates in Research* (Iron Age, Sept. 9, 1926, vol. 118, pp. 673–676). A review of the work of the United States Bureau of Standards in metallurgical investigations.

J. N. Greenwood, *The Equipment of the Metallography Department of the Melbourne University* (Commonwealth Engineer, May 1926). An illustrated description is given of the equipment of the furnace room, the mechanical testing laboratory, and the metallographical and research laboratories.

Brown-Boveri Works, Baden (American Machinist, European Edition, July 3, 1926, vol. 64, pp. 215–220). A description of the works and testing department of Messrs. Brown-Boveri's works at Baden.

W. H. Wills, jun., *The Laboratory as a Factor in the Inspection of Alloy and Tool Steel* (Transactions of the American Society for Steel Treating, May 1926, vol. 9, pp. 755–772). A brief outline is given of laboratory methods for the inspection and testing of tool steels.

R. A. Fiske, *Wheel Makers Expand Laboratory* (Iron Age, Sept. 23, 1926, vol. 118, pp. 838–840). Illustrated particulars are given of the equipment of the metallographical laboratory of the Association of Manufacturers of Chilled Car Wheels, at the Sacramento Square plant of the Griffin Wheel Co., Chicago.

CHEMICAL ANALYSIS.

Analysis of Iron, Steel, and Alloys.—J. T. Mackenzie, *Determining Carbon in Cast Iron* (Iron Age, Aug. 12, 1926, vol. 118, pp. 415–416).—The author describes a simplified form of combustion train in use in the laboratory of the American Cast Iron Pipe Co., Birmingham, Alabama. It consists of standard equipment except for a chromic-sulphuric acid bulb. It is easily maintained, and especially adapted to routine service.

A. Kling and A. Lassieur, *The Estimation of Sulphur in Siderurgical Products* (Chimie et Industrie, May 1926, vol. 15, pp. 699–701). During some work carried out on the standardisation of samples of hæmatite pig for the Société des Échantillons-Types pour Analyses, the authors found that, whereas close agreement was obtained between investigators using precipitation methods, there were very wide variations between the results of ten laboratories employing methods in which the sulphur was evolved in some other form. These variations could not be due to heterogeneity of the samples, because the results for carbon, manganese, and silicon were very concordant. Two experimenters came to the conclusion that concentrated hydrochloric acid must be used for the attack of the metal in "evolution" methods; dilute acid gave lower results according to the degree of dilution. The authors made comparative tests on the Bureau of Standards gravimetric method, on Campredon's modification of Arnold's method, and on an "evolution" method. The two former gave consistent and reliable results, but it was found that for the evolution method to succeed care must be taken of several points. They describe a method which gave good results, but show by other tests how slight deviations from the strict conditions caused high or low reports. The sulphur, evolved as H_2S, was absorbed in zinc acetate solution; the resulting ZnS was treated with a known quantity of iodine ($ZnS + I_2 = ZnI_2 + S$) and the excess iodine was titrated with a solution of sodium thiosulphate. The same trouble was not experienced with steels, and good agreement of results was easily attained.

P. Oberhoffer, *Determination of Oxygen in Iron* (Stahl und Eisen, Aug. 5, 1926, vol. 46, pp. 1045–1049). The author describes alterations and improvements in the various apparatus and in his procedure for the determination of oxygen in iron, by the hydrogen, the hot extraction, and the residue methods. The hydrogen apparatus was perfected, the influence of the form of test-piece was examined, and the tests to determine the reducibility of manganic oxide, in the quantities

as found in steel, were repeated. (For the former experiments see Stahl und Eisen, 1925, vol. 45, p. 1555.) In the residue process using bromine, if manganese is present the results do not show agreement. The improved iodine process of Eggertz is more promising. The results of these processes for the determination of silica show satisfactory agreement with those of the chlorination process, but it is not possible to determine iron at the same time as silica by the latter process. In a series of analyses of tool steels of different qualities by the residue process using bromine, the results show good quantitative agreement.

P. Klinger, *Determination of Gases in Iron and Steel* (Stahl und Eisen, 1926, vol. 46; Sept. 16, pp. 1245–1254; Sept. 23, pp. 1284–1288; Oct. 7, pp. 1353–1356). After reviewing the researches of previous investigators the author describes experiments made with a view of testing the results obtained by other workers in the determination of gases in iron and steel. Ten methods were followed, two of which were by hot extraction under vacuum, one without making additions to the molten metal, the other after making additions. The other eight were chemical solution or conversion methods.

E. Schiffer, *Determination of Cobalt and Other Constituents in Cobalt and Cobalt Steels* (Stahl und Eisen, 1926, vol. 46, p. 660; Report No. 49 of the Chemists' Committee of Verein Deutscher Eisenhüttenleute).

N. Tschischewski, *Analysis of Boron Alloys* (Industrial and Engineering Chemistry, June 1926, vol. 18, pp. 607–608). A rapid and accurate method for estimating boron is described. Iron and other metals are precipitated from a sulphuric acid solution by electrolysis; the resulting solution containing sulphuric and boric acids is titrated with caustic soda, the difference in behaviour of methyl orange and phenolphthalein towards the weak boric acid being made use of. Solution of the material for analysis is brought about in a flask under a reflux condenser on account of the volatility of the boric acid.

A. Kropf, *Estimation of Manganese in Special Steels, with Particular Reference to the Silver Nitrate-Persulphate Method* (Chemiker-Zeitung, June 1925, vol. 49, pp. 537–539). With more than 15 per cent. of manganese present, the silver nitrate-persulphate method cannot be applied, because of the small sample that must be taken. Neither can it be used when cobalt is present, because that element is peroxidised, and in acid solution is reduced again partially, reacting with some of the permanganate formed. In the latter case the cobalt and manganese must be separated by the chlorate method, in which MnO_2 is precipitated, the cobalt chlorate remaining in solution. A list is given of the various types of steels for which the silver nitrate-persulphate method is suitable.

A. D. Funck, *Colorimetric Determination of Molybdenum* (Zeitschrift für analytische Chemie, 1926, vol. 68, pp. 283–286). Describes a method of estimating molybdenum depending on the formation of brownish-red

permolybdate by the addition of hydrogen peroxide to the alkaline molybdate solution. The intensity of the colour is proportional to the concentration of the molybdenum and hydrogen peroxide, but is unaffected by excess of alkali. Chromates and tungstates interfere. In analysing ferro-molybdenum the material is attacked with nitric acid, and the insoluble residue is fused with sodium carbonate; the solution after leaching the melt is evaporated, together with the nitrate solution, to dryness; the residue is treated with an excess of sodium hydroxide, again dried and ignited for a few minutes. The mass is dissolved in water, and an aliquot portion is used for the colorimetric estimation.

A. P. Rollet, *Colorimetric Determination of Nickel* (Comptes Rendus, 1926, vol. 183, pp. 212–213). The difficulties involved in Feigl's method of determining nickel are surmounted by adding to the solution a small excess of bromine water. The excess of the latter is absorbed in ammonia, a few drops of alcoholic solution of dimethylglyoxime are added, and the resulting colour is matched after two minutes. If cobalt is present, it must be obtained in the form of sodium cobalticyanide, and the yellow colour of this may then be compensated for in the standard. For use with steels the reagent must be added before the ammonia to avoid the carrying down of the nickel by the precipitated ferric hydroxide.

M. Kolthoff and O. Thomisek, *Potentiometric Estimation of Vanadium and of Chromium in Presence of Iron; Employment of the Method in the Analysis of Steel* (Recueil des travaux chimiques des Pays-Bas, May 1924, vol. 43, pp. 447–456). The authors describe a potentiometric method of titrating vanadium and chromium in presence of iron. The vanadium and chromium, in solution in mixed sulphuric and nitric acids, are peroxidised by ammonium persulphate; any manganese present will not be peroxidised until after the other two metals, consequently the appearance of the permanganate pink colour is an indication of sufficient ammonium persulphate. The vanadium and chromium are reduced by ferrous sulphate in excess. Permanganate solution is then run in under potentiometric control, and the first inflexion in the curve indicates the oxidation of all the excess ferrous iron. The solution is then heated to 70° to 80° C. and the permanganate added until a second inflexion in the curve occurs. This shows that all the vanadium has been oxidised, the chromium being unaffected while any vanadyl compound remains. The difference between the titres at the first and second inflexions, of course, gives the vanadium titration. The chromium is calculated by difference between the vanadium and vanadium + chromium, the latter being obtained by titrating potentiometrically the peroxidised elements with ferrous sulphate in sulphuric acid solution.

Analysis of Ores and Slags.—H. P. Hollnagel and E. A. Harty, *Can the Hardness of Materials be Neglected in Granulometric Sieve Analysis?* (Paper read before the American Society for Testing Materials,

June 1926). The authors describe a series of tests which indicate that the continuous rubbing of a soft material on the sieve wires causes it to crumble, so that if the operation of sieving be continued all material will ultimately go through the finest mesh sieve. The tests lead to the conclusions that materials of different degrees of hardness should be shaken for different lengths of time, and that some standardisation should be effected with reference to the manner and time in which sieve analyses should be made.

E. Dittler, *Determination of Chromium in Chromiferous Iron Ore* (Zeitschrift für angewandte Chemie, 1926, vol. 39, p. 279). Comparative determinations of chromium by titration with permanganate, using various reagents, such as sodium thiosulphate.

B. Clark, *The Bismuthate Method for Manganese* (Industrial and Engineering Chemistry, June 1926, vol. 18, pp. 597–598). In the usual bismuthate method of estimating manganese the oxidation of the manganese is carried out in a solution containing nitric acid. This method has certain defects: (*a*) The oxides of nitrogen must be removed; (*b*) the permanganic acid is not so stable in the nitric acid solution as is desirable; (*c*) the temperature during oxidation must be kept low; (*d*) nitric acid has a tendency to react with ferrous iron. The purpose of this paper is to show that sulphuric acid, which introduces none of these defects, may be substituted for the nitric acid. A rapid and accurate method on these lines for the determination of manganese in iron ores is given.

L. Brandt, *A New Method for the Determination of Iron with Titanium Chloride in Presence of Copper* (Stahl und Eisen, July 22, 1926, vol. 46, pp. 976–981). The method is fully described and has proved to be very suitable for the estimation of iron in ores, giving more accurate results than other methods in common use.

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part IV.—On the Reducing Action of Bismuth Amalgam, the Reduction of Uranium, and the Application of Dichromate Titration* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 399–415).

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part V.—Estimation of Phosphoric Acid by Means of a Uranyl Salt* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 417–420). A new method for the estimation of phosphoric acid was devised in which uranyl ammonium phosphate thrown down in a crystalline form is dissolved in hydrochloric acid, reduced with zinc or bismuth amalgam and titrated with potassium dichromate, using diphenylamine as indicator.

K. Someya, *The Use of Liquid Amalgams in Volumetric Analysis. Part VI.—Estimation of Chromic Acid, Ferric Iron, and Ferricyanide by a Titanous Salt* (Science Reports of the Tôhoku Imperial University, 1926, vol. 15, pp. 421–426). Titanous sulphate was prepared by the amalgam method and was used in the titration of chromic acid, a mixture of ferric iron and chromic acid, and of ferricyanide, using

diphenylamine as indicator. Diphenylamine was found to be also applicable in the case of the stannous chloride titration of ferricyanide.

H. H. Shepherd, *The Examination and Analysis of Cupola Slag* (Foundry Trade Journal, 1926, vol. 34; July 29, pp. 99–100; Aug. 12, pp. 141–142; Aug. 19, pp. 161–162). The author describes the procedure for the accurate and complete analysis of slags.

Analysis of Gas.—F. G. Hofllann, *Liquids used for Displacing Gases in Gas-Analysis Apparatus* (Feuerungstechnik, 1926, vol. 14, pp. 98–101). A discussion of the relative merits and efficiencies of some of the liquids used for displacing gases in gas-analysis apparatus. The solubility of carbon dioxide is a matter of considerable importance for the accuracy of the results, and figures for its solubility in various liquids are quoted.

H. Davies and H. Hartley, *The Determination of Traces of Carbon Monoxide* (Journal of the Society of Chemical Industry, June 4, 1926, vol. 45, pp. 164–168; Gas Journal, June 9, 1926, vol. 174, pp. 530–532). Description of a sensitive method of determination of carbon monoxide by means of its reaction with iodine pentoxide, developed by the research staff of Radiation Ltd.

J. Sveda, *The Analysis of Combustible Gases by Combustion by Means of Copper Oxide* (Chemicke Listy, 1925, vol. 19, pp. 48, 79). In this method the combustion of the gases is brought about by means of heated copper oxide in the absence of air or oxygen. The "combustor" consists of a small unglazed porcelain crucible heated by a platinum wire and containing a mixture of copper oxide with a little ceria. The latter substance prevents the agglomeration of the reduced copper so that the combustor may be regenerated by simply heating it in air. The determination is carried out in an eudiometer; the temperature is raised to 280° to 290° C. by passing an electric current through the resistance, and the complete combustion of hydrogen and carbon monoxide takes place in half an hour. The results for hydrogen obtained on a mixture of hydrogen and nitrogen are quantitative. The combustion of carbon monoxide is also complete, but an error is introduced owing to the greater degree of adsorption of CO_2 than of N_2, resulting in too small a volume of residual gas. If the CO_2 be absorbed by potash there remains no more nitrogen than was in the original mixture.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

Benedicks, C. "*Metallographic Researches, based on a Course of Lectures in the United States in* 1925." 8vo, pp. xi + 307, with 153 figures in the text. New York and London, 1926: McGraw Hill Publishing Company, Ltd. (Price $4.)

This book is based on a course of lectures delivered by the author in the United States in 1925, which were afterwards collected and printed with additional matter not previously published, or published only in part in Swedish. The first lecture deals with the kinetic constitution of solid matter, in which the fundamental idea is developed that the coll sions of the atoms cause a definite mean distance between the atoms without the intervention of any special repulsive forces, a theory which involves important considerations. In another lecture the theory of hardness of steel and other alloys is reviewed, the increase in hardness on cold-working is explained, and the salient points concerned in the allotropy of iron are briefly pointed out. In another lecture on meteoric iron and invar, a brief account is given of the author's synthesis of the constituents of meteoric iron, the main result of the work being the establishment of the fact that nickel-iron alloys with low nickel content possess a duplex or two-phase structure. The author's work on high-power microscopy is well known, and some account of the apparatus employed is given, and the remarkable effects produced are shown. In another lecture the author describes the interesting discovery by A. Grabe of the first recorded observations of the critical point Ac in steel. Scientific research in regard to metals flourished in Sweden at the end of the eighteenth and at the beginning of the nineteenth century. In 1767 the Royal Swedish Patriotic Society was founded, which a few years later started the publication of a monthly journal, the *Journal of Economy.* In one of the first numbers of this journal (in 1777) Johan Frederiksson Angerstein reported his experiments, having for their object the improvement of cutlery steel, and he there describes the decalescence point of carbon steel, laying stress on its immediate practical interest in enabling the smith to obtain the very best hardening qualities. Other subjects of practical importance are dealt with in the book, including a determination of the specific gravity of molten iron, the designing of a rational ingot section for hard-rolled material, and the action of the hot wall as a chief factor influencing the rapid corrosion of water-tubes.

The book is an important contribution to the science of the metallurgy of iron and steel.

Evans, U. R. "*The Corrosion of Metals.*" Second edition. 8vo, pp. xvi + 259, with 28 diagrams and 1 plate. London, 1926: Edward Arnold & Co. (Price 15s.)

Progress in research on corrosion processes, and the increased knowledge of those processes gained by such research, have been so rapid that a second edition of this work has become necessary within two years after the appearance of the first in 1924. Many additions have been made to the book as originally written, but the author has preserved the general arrangement of the first edition, giving a concise statement of the subject in the text,

accompanied by numerous references in footnotes to papers and publications in which fuller details can be found if desired. The book opens with an historical survey of the subject, and concise information is presented concerning certain elementary facts of electro-chemistry. Throughout the volume abstruse mathematics are almost entirely avoided, and where more detailed description of some matter, involving the use of symbols, has seemed desirable, the necessary treatment has been compressed into a footnote. In the body of the book examples are given of different types of corrosion, sometimes of one metal, sometimes of another. An Appendix has therefore been added in which the individual metals are discussed seriatim, the behaviour of each metal towards the most important corrosive agencies being summarised very briefly, and in contrast with earlier chapters, no attempt is made to suggest causes for the facts enumerated.

HADDOCK, M. H. "*The Location of Mineral Fields: Modern Procedure in the Investigation of Mineral Areas and the Subsequent Verification of their Extent, &c.*" 8vo, pp. vi + 295, with 10 folding plates and 213 figures in the text. London, 1926: Crosby Lockwood & Son. (Price 9s. 6d.)

This new work is concerned with the science of prospecting and surveying of mineral deposits generally, and in particular with the means and methods for inferential location of mineral fields. The subjects are dealt with under the following headings: The application of planes in mining, contouring, the form of outcrop and mineral mapping practice, bore-hole surveys and problems, faulting and folding, applied geophysics, spherical trigonometry and astronomical methods, triangulation and correlation. The location of minerals by surface methods is a comparatively new science, by which an enormous saving in organised drilling is effected. The magnetic and electrical methods of locating minerals are described, special attention being given to the Lundberg-Nathorst (equipotential) method; the Lindblad-Sundberg-Vos (electro-magnetic) method; the Schlumberger (potential or intensity) method. The gravitational methods are also described. The book is concisely written, and the clear definitions of terms employed in mine surveying practice and geology are a useful aid for students of the subject. The work is based on the results of observations in many mineral fields, and indicates a fairly wide acquaintance with mining conditions of different types.

HANEMANN, H., and A. SCHRADER. "*Ueber den Martensit.*" Mitteilung aus der Metallographischen Abteilung des Eisenhüttenmännischen Laboratoriums der Technischen Hochschule zu Berlin. (Sonderheft der *Berichte der Fachausschüsse des Vereins deutscher Eisenhüttenleute:* Werkstoffausschuss. Bericht Nr. 61.) La. 8vo, pp. 25, with 77 illustrations in the text and 13 tables. Düsseldorf, 1926: Verlag Stahleisen m.b.H. (Price 6 marks.)

This report constitutes Report No. 61 of the Technical Committees of the Verein deutscher Eisenhüttenleute, the work having been mainly carried out in the metallographic section of the Iron Metallurgical Laboratory of the Technical High School at Berlin. The authors present a review of previous investigations regarding the structure of martensite and austenite in hardened steels, their thermal expansion and critical points. The current opinion is that martensite is alpha-iron, whose space lattice has been strained by an unstable solution of carbon within the lattice. It is pointed

out that the established facts of the austenite-martensite reaction cannot be reconciled with the alpha-iron hypothesis, and it is concluded that when austenite changes to martensite in quenched steel there is a change in the carbon content of the austenite and the martensite. Besides austenite and ordinary ferrite, two formations, epsilon and eta, are found in quenched steel, and these two are in metastable equilibrium with the austenite. The martensite contains less carbon than the austenite with which it is in contact. A constitution diagram showing the lines of the metastable martensite system is given. For the experiments, small pieces of soft Krupp iron containing 0·07 per cent. carbon were used. A description of the seventy-one micrographs is given.

HURST, J. E. "*Metallurgy of Cast Iron: A Complete Treatise for Engineers, Foundrymen, and Students.*" 8vo, pp. xvi + 311, with 116 figures in the text, including numerous micrographs. London, 1926: Sir Isaac Pitman & Sons, Ltd. (Price 15s.)

The importance of a knowledge of the constitution and properties of grey cast-iron is better realised when it is considered that by far the larger bulk of all ordinary machinery consists of grey iron castings. This book has therefore been compiled for the use of foundrymen and engineers, with the prime object of conveying an idea of the factors influencing the mechanical and physical properties of grey cast-iron. The author deals fully with the nature and constitution of iron-carbon alloys, the formation of graphite in such alloys, and the influence of other elements, such as silicon, sulphur, manganese, phosphorus, and special alloy metals. Further chapters discuss the heat treatment and volume changes, influence of the rate of cooling and casting temperature, and the shrinkage and contraction of cast-iron. The manner in which all these conditions affect the mechanical and physical properties of the castings is treated at considerable length. Finally, the mixing of irons, the use of steel additions, and the practice of casting iron in permanent moulds, are dealt with. The book is a useful and practical addition to the literature on the metallurgy of cast-iron.

"*Hütte: Des Ingenieurs Taschenbuch.*" Herausgegeben vom Akademischen Verein Hütte E.V. in Berlin. 25 neubearbeitete Auflage. II. Band. 8vo, pp. xx + 1167, illustrated. Berlin, 1926: Verlag von Wilhelm Ernst & Sohn. (Price: 14.70 marks, cloth bound; 17.17 marks in calf.)

The first volume of the twenty-fifth edition of this important publication which first appeared fifty years ago was published in 1925. As in the case of the earlier revised volume, the pocket-book has been completely revised and brought up to date so as to include notes on the progress of applied science in the engineering industry in all countries. The following are the principal sections of the book, and the names of the respective authorities who have compiled the information:—I. Component Parts of Machines, revised by Professor Kutzbach. II. Prime Movers, revised and enlarged by Professor Atzler. Under the heading of "The Live Motor," Professor E. Atzler deals with human energy and the physiological factors involved in the performance of work by men and draught animals. The chapter on Wind Turbines for agricultural purposes has been prepared by Professor R. Vogdt, and another on Steam Boilers is the work of the Engineers Generlich, Martens, and Wentzel. Steam-Engines are dealt with by Professor Doerfel and Professor Körner, and the chapter on Steam-Turbines has been revised by P. Wagner and Professor R. Doerfel. Combustion Motors: this chapter was edited by Professor Kutzbach; the chapter on

Gas-Turbines was prepared by Professor G. Stauber, and Water-Motors by Professor D. Thoma. The remaining sections deal with machine tools, lamps and illumination, and electro-technics, all of which subjects have undergone revision and enlargement in bringing them up to date. The last-named section has been supplemented by a new chapter on the technology of electric heating. Throughout the book the new standard dimensions and standard shapes as laid down by the German National Standards Committee have been adopted.

Like the previous volume, the present one contains a vast store of information based upon experience gained in actual practice, and it constitutes a most useful work of reference to all engaged in any branch of engineering work.

Kirsopp, J. "*The Use of Power in Colliery Working.*" A treatise on Mining Costs and Machinery Designs and Management. 8vo, pp. xxviii + 579, with 365 illustrations. London, 1926: H. F. and G. Witherby. (Price 40s.)

The author, who is well known as a certificated colliery manager and mining engineer, covers wider ground than is indicated by the title of his book. Practically every detail of power equipment in a colliery is dealt with, and the discussion of general considerations, such as boilers, mechanical stoking, low-grade fuel, pulverised fuel, turbines and generation of electrical power, is followed by chapters dealing with wire winding ropes, pumping, and haulage. The subject of wire ropes is exhaustively treated, the standard specification, physical properties, testing, and designs of ropes being carefully noted. At the end of the volume there are five appendices, in the first of which are given the average prices of materials and stores in each of the years 1913 to 1925. The second deals with labour conditions, and contains a series of tables showing the average weekly and daily wages for the period 1913 to 1925 of twenty different trades, including the different classes and grades of railwaymen and of men in the building trades. Appendix 3 comprises a table of the various sub-products of coal, and the yield of coke obtained by high-temperature carbonisation. Appendix 4 presents a detailed comparison of the pre-war and present costs of sinking and equipping a colliery, while Appendix 5 constitutes an addendum to the chapter on pumping. The book should form a useful work of reference for the practical engineer and general manager, and the economic information should appeal to a still wider class.

Litinsky, L. "*Feuerfeste Baustoffe für Kammern der Kokerei- und Gaswerksöfen.*" 8vo, pp. 50, and 15 figures in the text. Halle (Saale), 1926: Wilhelm Knapp. (Price 2.80 marks.)

The pamphlet is intended to serve as a guide to the selection of materials suitable for the construction of coke-oven chambers and gas retorts. A classification of acid and basic refractory materials is given, and the text contains tables showing the chemical composition of the materials in common use for the manufacture of silica bricks and fireclay bricks, with notes on the behaviour of such bricks in service.

Pralle, E. "*Die Kaolinlager in Schlesien.*" 8vo, pp. 50, with 9 figures in the text. Halle (Saale), 1926: Wilhelm Knapp. (Price 3.60 marks.)

This work forms Volume VII. of the collection of treatises on practical geology and mining technology, edited by Dr. Georg Berg, Berlin. The work describes the geological conditions, occurrence and composition of the kaolin deposits found in certain districts of Silesia, and discusses their economic importance.

SMITHELLS, C. J. "*Tungsten: A Treatise on its Metallurgy, Properties, and Applications.*" 8vo, pp. viii + 167, with 156 figures in the text, including numerous micrographs. London, 1926: Chapman and Hall, Ltd. (Price 21s.)

This is an excellent text-book, dealing generally with the metallurgy of tungsten. The author gives a clearly written account of the preparation of tungstic oxide from tungsten ores and the reduction of the metal tungsten from its oxide, followed by a brief history of the developments of the manufacture of tungsten filaments, and how success was at last achieved by Coolidge in producing ductile tungsten. A description of present-day practice in the manufacture of tungsten filaments and of their widespread use in the electric lamp industry is given, and the metallography of the metal is well illustrated.

The question of the industrial application of tungsten is dealt with mainly from the point of view of the electrician and physicist. The use of the metal tungsten as filaments for incandescent lamps is undoubtedly a most important practical development, out of which an extensive industry has grown up, but by far the largest quantity of the tungsten produced is used in the manufacture of alloy steels, particularly high-speed tool steel and magnet steel. This aspect of the subject is very lightly treated by the author and, with the exception of the work of Evershed on magnet steels, no reference is made to the extensive researches of other British investigators on the uses of tungsten as an alloy metal. The work, in fact, is mainly devoted to the metallurgy of tungsten, its manufacture, metallography, and the practical applications of metallic tungsten.

"*Tables Annuelles de Constantes et Données Numériques de Chimie, de Physique et de Technologie: Art de l'Ingénieur et Métallurgie.*" Résistance des Matériaux et Données Numériques diverses, rédigées par L. Descroix. Préface de Sir Robert Hadfield, Bart., F.R.S. Extrait du Volume V. 4to, pp. x + 1659–1909. Paris, 1926: Gauthier-Villars et Cie; London: Cambridge University Press; Chicago: University of Chicago Press.

This work is published under the patronage of the International Research Council and the International Union of Pure and Applied Chemistry, with the supervision of Dr. Charles Marie, General Secretary. Volume V., of which the present extract forms a part, follows Volume IV., published in 1922. The aim of this publication, as pointed out on previous occasions, is to collect data published under different auspices and in a much disseminated form in many countries. These data are liable in many cases to be overlooked, owing to the great difficulty often experienced by those most in need of the facts, who have to spend time in laboriously searching them out. The work falls into two parts: (1) "Engineering," which includes the mechanical constants for a great variety of materials in common use for structural and other purposes, and the thermal constants of refractory materials and fuels; (2) "Metallurgy," which includes technical data concerning metals and alloys, their mechanical constants, and electric and magnetic properties.

THORPE, W. H. "*Steel Bridge Weights: Being Particulars of* 133 *Examples, with Diagrams based thereon.*" Obl. 8vo, pp. 35, with 12 figures in the text and 2 folders. London, 1926: Crosby Lockwood & Son. (Price 7s. 6d.)

The importance of reaching a near estimate of the weight of steel in any bridge is well known to experienced designers. In the case of small

bridges, some discrepancy in the assumed weight may be of little importance, as the total weight of steel used is small. But in the case of large spans, the weight of the structure may greatly exceed that of the load to be supported, and the effect of any miscalculation of the weight may then become serious, rendering necessary a laborious revision of the whole design. It is apparent that weights of steel based upon actual examples will have the advantage of including all the factors which go to make up the total weight of steelwork in a structure, and with this object in view an attempt is made by the author to furnish, by the aid of diagrams based on actual cases, a means of determining probable steel weights in bridges of various types by reference to the live load carried by the bridge.

TRINKS, W. "*Industrial Furnaces.*" Vol. I. Second edition. 8vo, pp. vii + 352, illustrated. New York, 1926: John Wiley & Sons, Inc.; London: Chapman and Hall, Ltd. (Price 22s. 6d.)

A second edition of this work has been necessitated by the favourable reception of the first one published in 1923, and the author has taken occasion to make certain additions to the volume in order to bring it up to date. The principal addition to the work is in the form of an appendix, into which has been gathered information concerning the more important recent developments in the field of industrial furnaces. The volume deals with the fundamental principles and facts which underlie all industrial heating operations, and the science and art of furnace design. Methods are laid down for the calculation of the size of a furnace to heat a certain amount of material in a given time to a given uniform temperature, and the heat losses due to various causes in furnaces worked under different conditions are investigated. The means employed to economise heat, and the heat consumption per unit of material, are exhaustively considered, and a chapter is devoted to the question of the maintenance of furnaces and the properties of the material which enter into their construction.

VEREIN DEUTSCHER EISENGIESSEREIEN, GIESSEREIVERBAND: "*Fachwörterbuch für das Giessereiwesen*" (Deutsch-Englisches und Englisch-Deutsches). Herausgegeben vom Verein deutscher Eisengiessereien, Giessereiverband. 8vo, pp. iv + 60. Düsseldorf, 1926: The Verein. (Price 3 marks.)

This handy German-English and English-German dictionary of technical terms used in foundry practice and in the foundry trade was compiled by the Associated German Foundries for the occasion of their visit to the International Foundry Exhibition at Detroit. The compilers have been at particular pains to include all words in daily use among workers in the foundry, and to find the corresponding English expressions. It is to be hoped that further issues of the book will appear with some amplification until it constitutes a really complete dictionary of the foundry trade in general.

VEREIN DEUTSCHER EISENGIESSEREIEN, GIESSEREIVERBAND: "*Giesserei Handbuch.*" Herausgegeben vom Verein deutscher Eisengiessereien, Giessereiverband. 2 Auflage. 8vo, pp. xii + 413, with 78 illustrations in the text and 100 tables. Munich and Berlin, 1926: R. Oldenbourg. (Price 18 marks.)

The first edition of this work appeared in 1921, and owing to the unexpectedly large demand a second was called for within a few months, but the general financial and economic conditions in 1922 and the years immediately following were too unfavourable to allow the work of a second

edition to proceed, so that the Associated German Foundries have only now been able to produce the long-awaited revised volume. The work is not a text-book in the ordinary sense, but is of the character of an encyclopædia for the German foundry industry. In the first section are set out all specifications relating to foundry products as adopted in the various countries and by Bureau Veritas, Lloyd's Register of Shipping, and the German Lloyd. Section 2 deals with technical data and the physical properties of cast-iron, testing appliances, and methods of testing. Section 3 discusses the raw materials used in the foundry, the classification of irons, composition of foundry pig-iron, and methods of analysis. Other sections follow dealing with cupola practice, moulding sands, and their essential properties and testing, and tables of standard dimensions of pipes and fittings. A most useful feature of the book is the inclusion of a table of German import duties at present in force on cast-iron ware, alloy metals and foundry materials generally, statistical tables, and finally a complete directory of German iron foundries, steel foundries, pipe foundries, foundries producing malleable castings, non-ferrous metal foundries, and a list of German firms owning blast-furnaces, giving the number of furnaces owned by each company and the capacity of the furnaces. The whole forms a valuable work of reference for the foundry industry, and in particular for the German foundry trade.

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